Cross Section and Double-Helicity Asymmetry in Charged Hadron Production at $\sqrt{s}$=62.4 GeV at PHENIX

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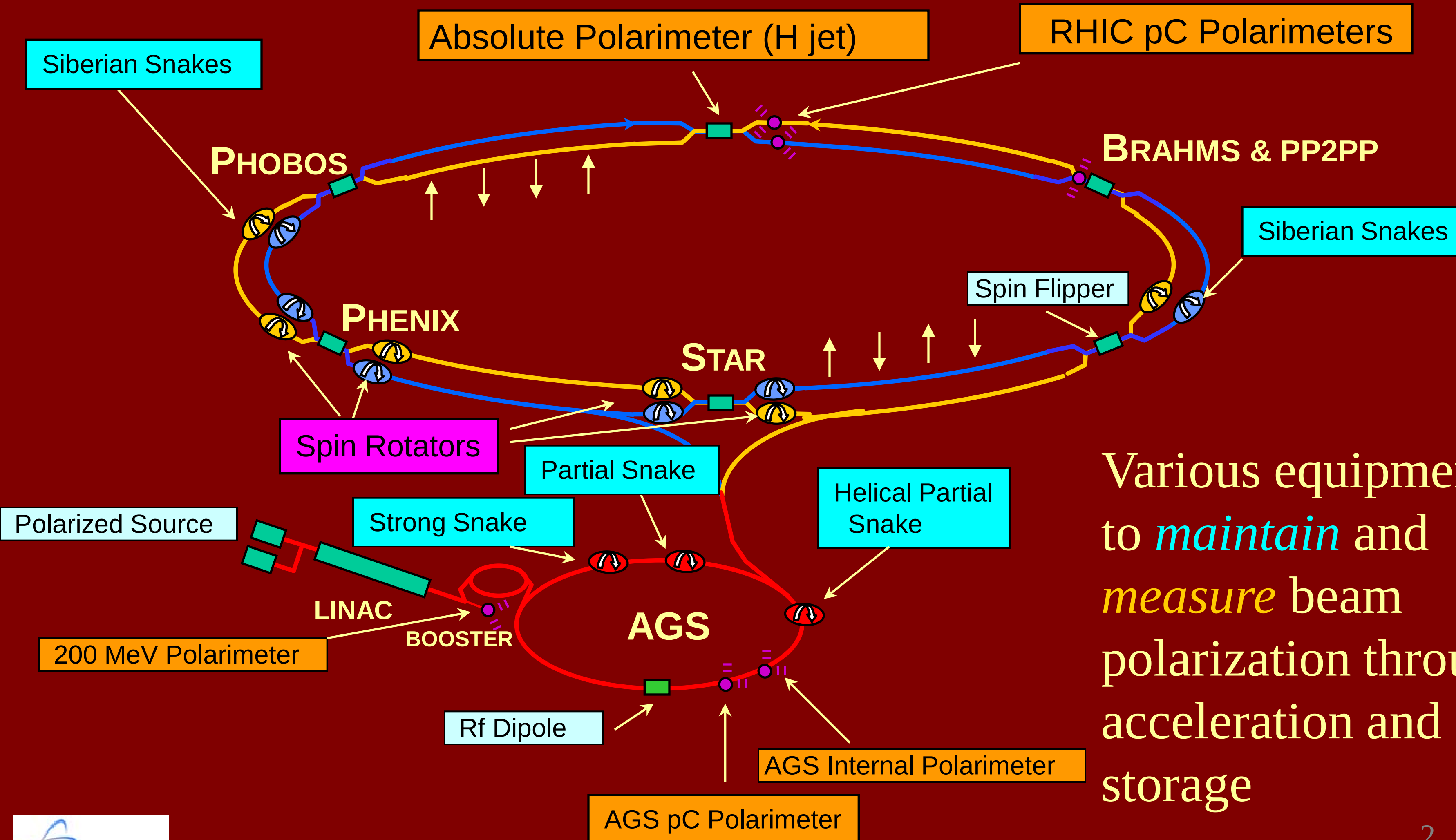
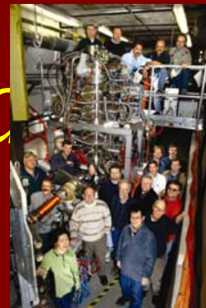
SPIN 2010, Juelich, Germany
September 28, 2010

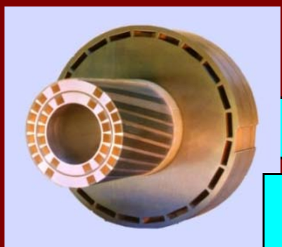
RHIC as a Polarized p+p Collider



Various equipment to *maintain* and *measure* beam polarization through acceleration and storage

RHIC a Polarize Collider





Absolute Polarimeter (H jet)

RHIC pC Pola

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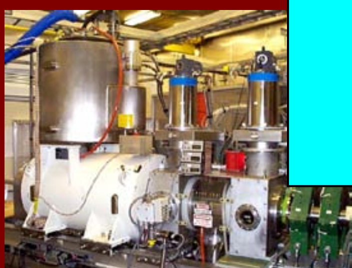
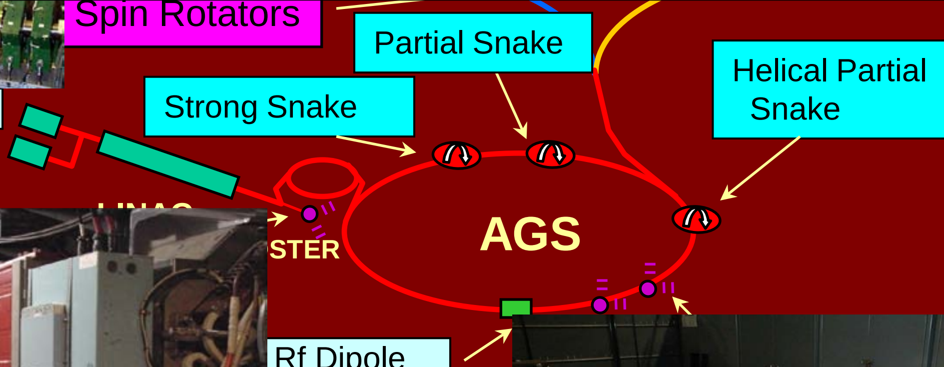
Overarching goal of RHIC spin program is to study nucleon structure in terms of (polarized) parton distribution functions (pdfs)

• High energies: $\sqrt{s}$ = 50-500 GeV

• Perturbative QCD framework





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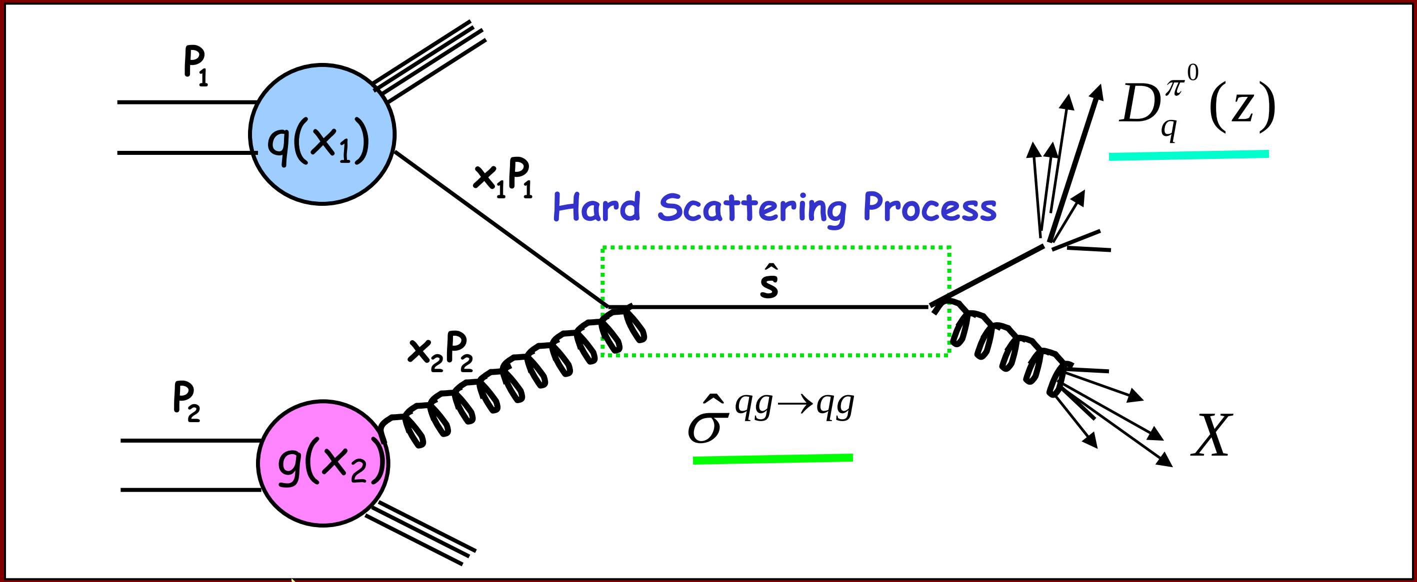
Predictive Power of pdf's:
Factorization and Universality in Perturbative QCD



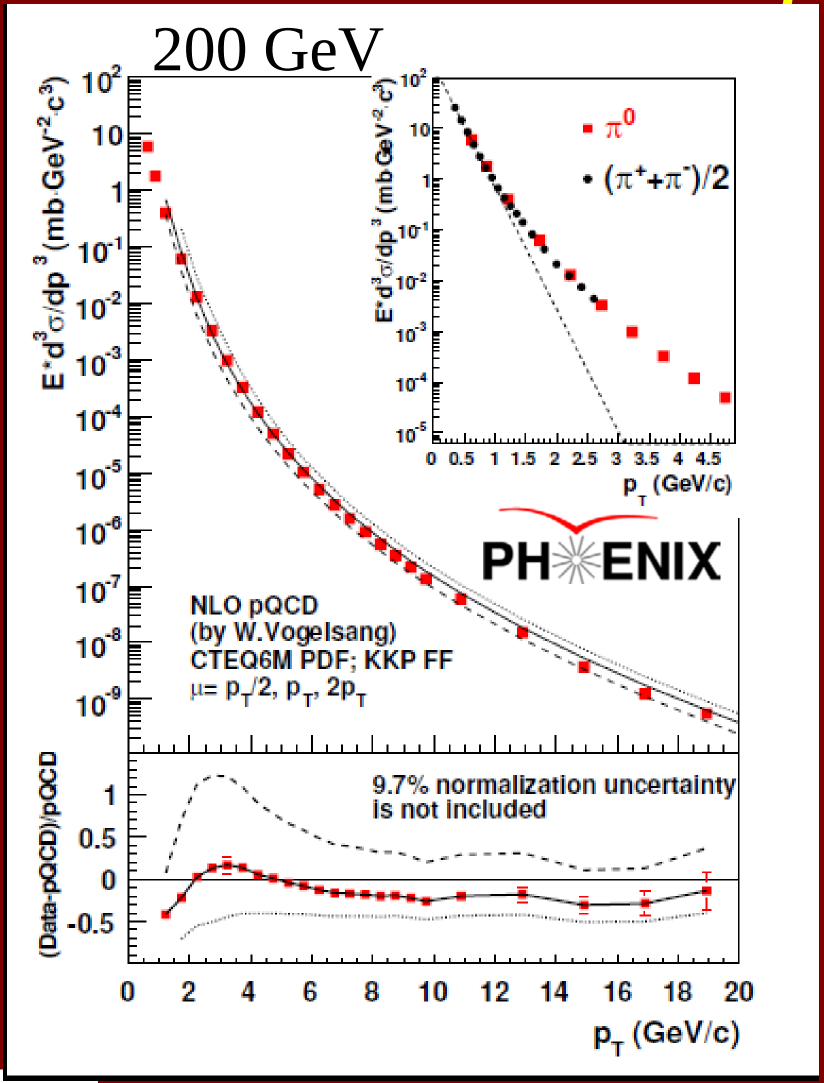
$$\sigma\left(pp \to \pi^0 X\right) \propto \underline{q(x_1) \otimes g(x_2)} \otimes \underline{\hat{\sigma}^{qg\to qg}(\hat{s})} \otimes \underline{D_q^{\pi^0}(z)}$$

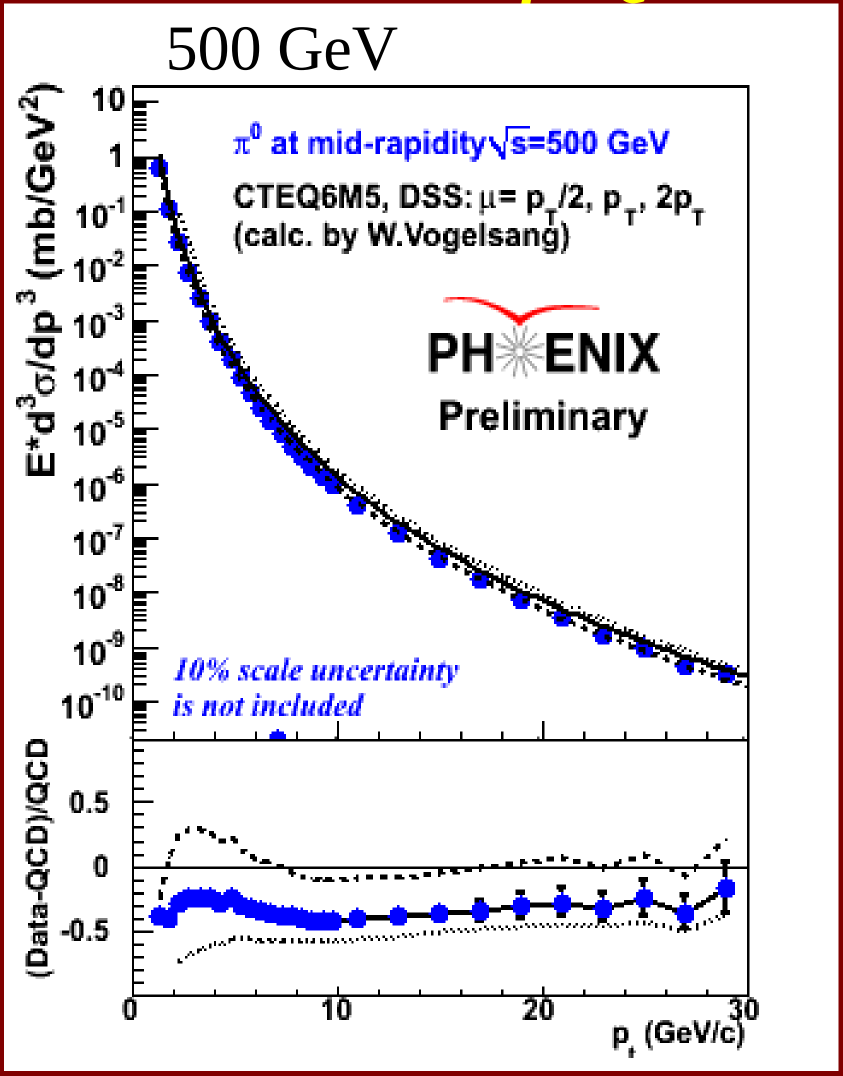
"Hard" probes have predictable rates given:

- Parton distribution functions (need experimental input)
- Partonic hard scattering rates (calculable in pQCD)
- Fragmentation functions (need experimental input)

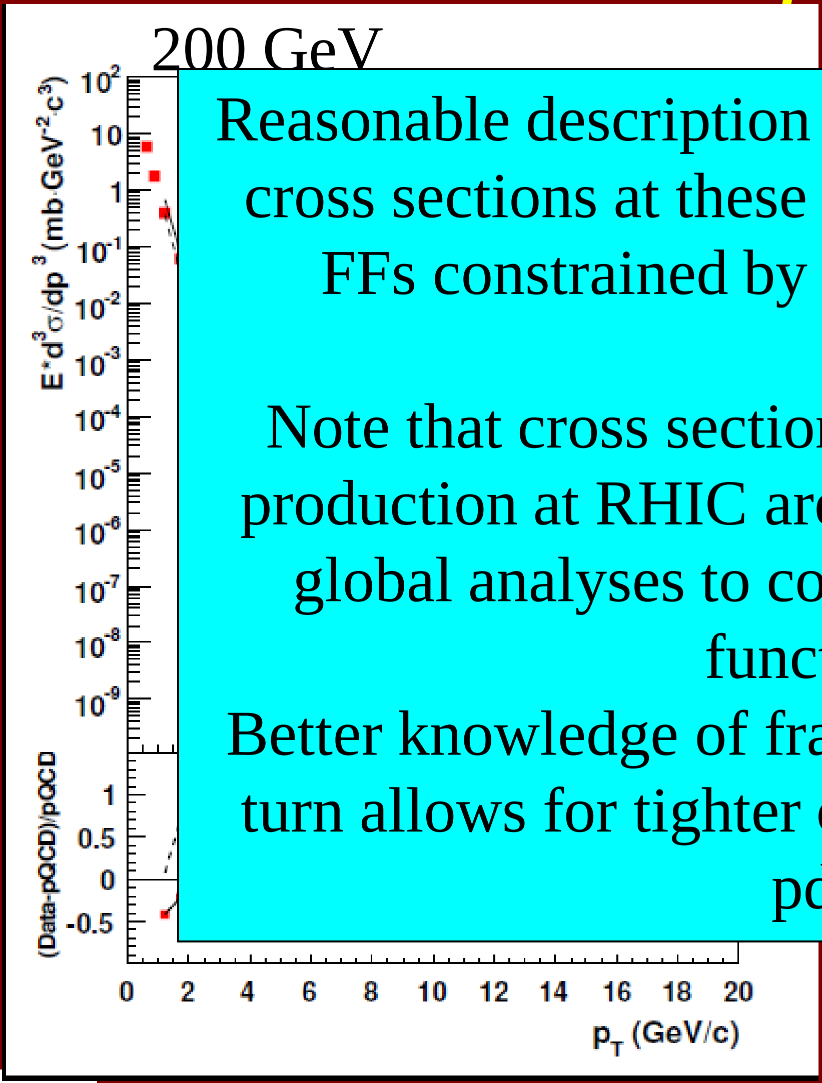
Universality (Process independence)

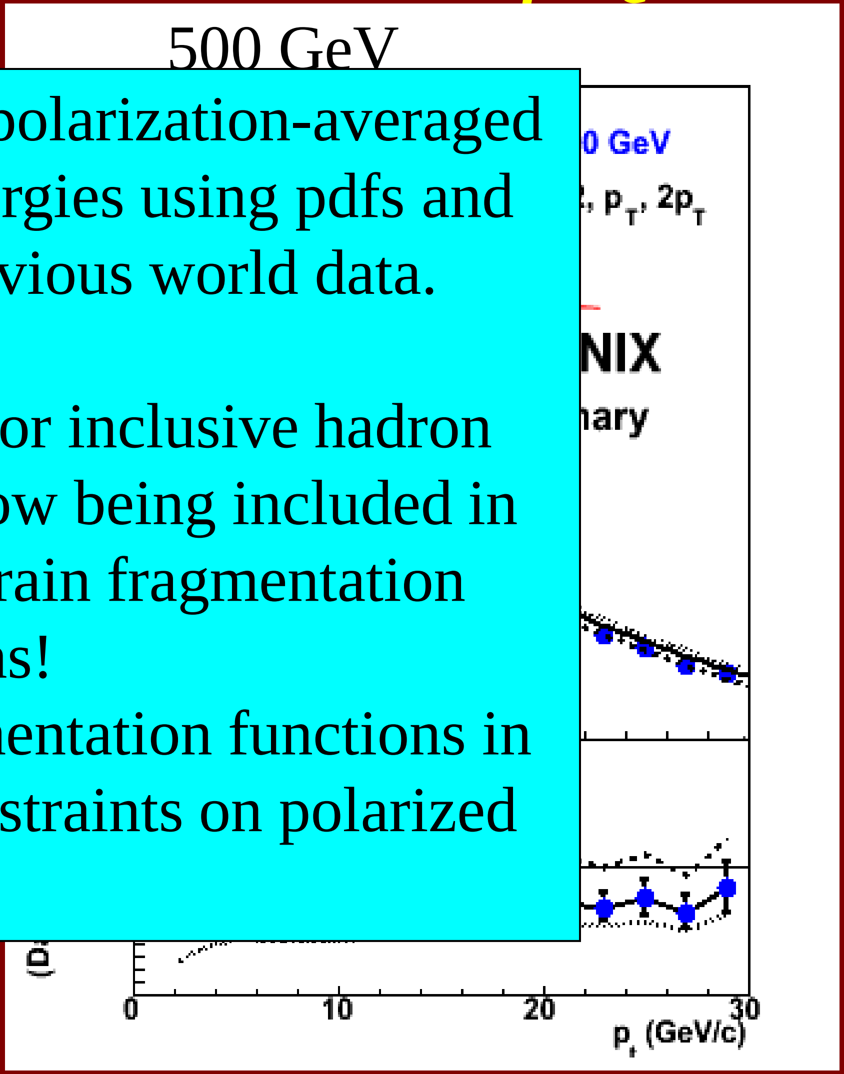
Midrapidity pion production at 200 and 500 GeV compared to NLO pQCD





Midrapidity pion production at 200 and 500 GeV compared to NLO pQCD





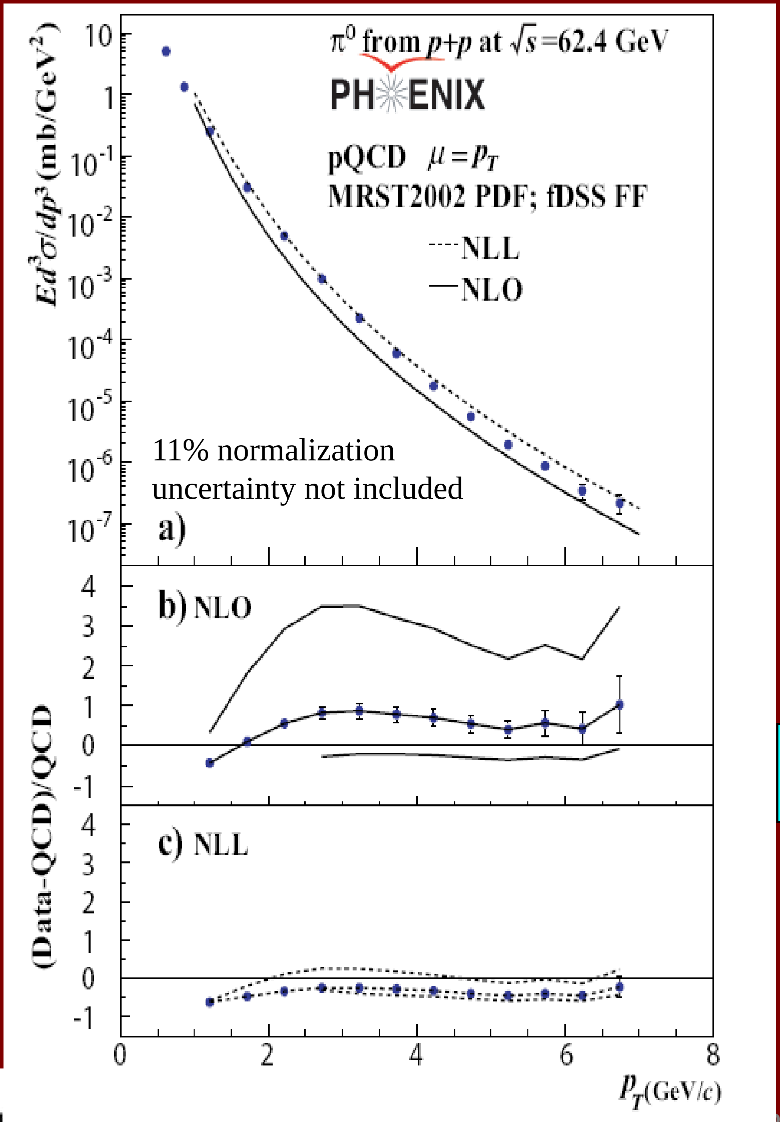
Reasonable description of polarization-averaged cross sections at these energies using pdfs and FFs constrained by previous world data.

Note that cross sections for inclusive hadron production at RHIC are now being included in global analyses to constrain fragmentation functions!

Better knowledge of fragmentation functions in turn allows for tighter constraints on polarized pdfs.

Lower energies: $\sqrt{s}$=62.4 GeV
Midrapidity π^0's

PRD79, 021002 (2009)



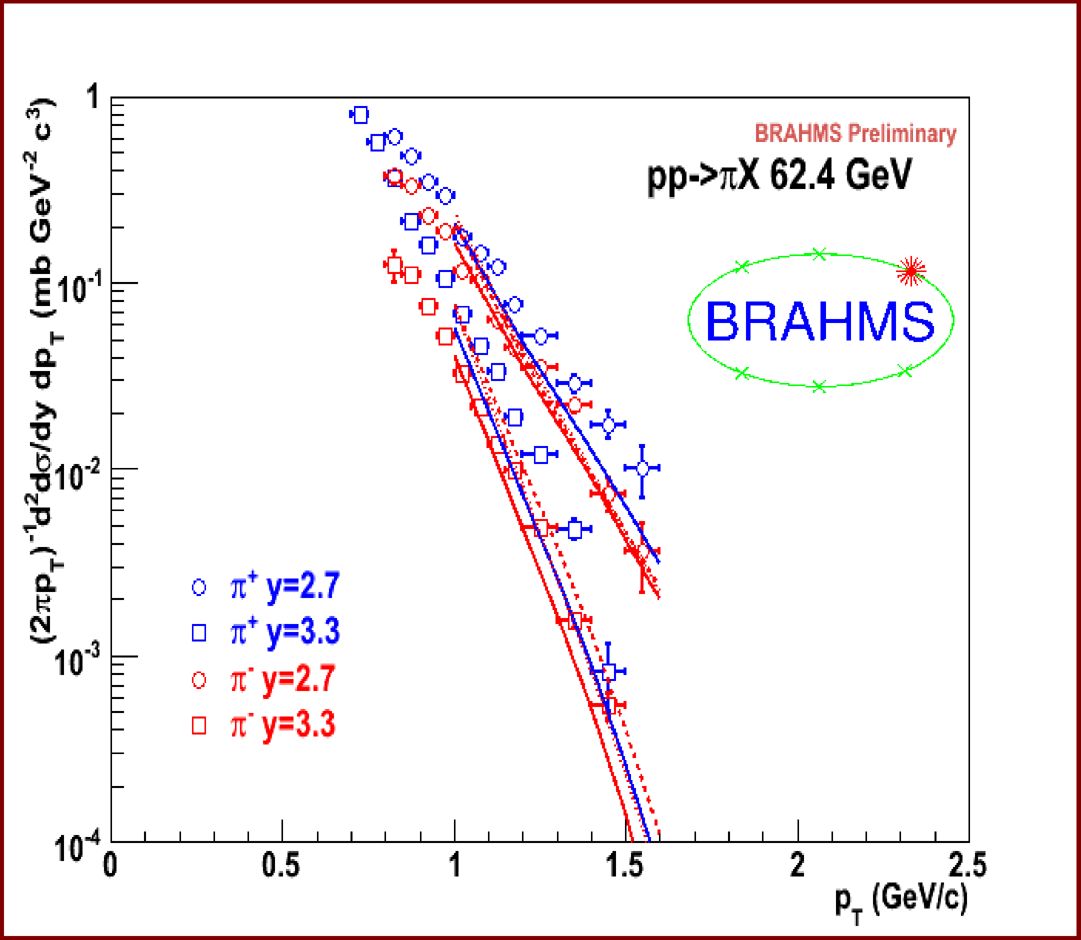
Comparisons to NLO and NLL pQCD calculations using $\mu=p_T$ shown.

Unlike at 200 GeV, scale choice of $\mu=p_T$ underpredicts the data.

→ Threshold logarithm effects still relevant at this intermediate energy?

But—overall, pretty good agreement!

$\sqrt{s}$=62.4 GeV
Forward pions



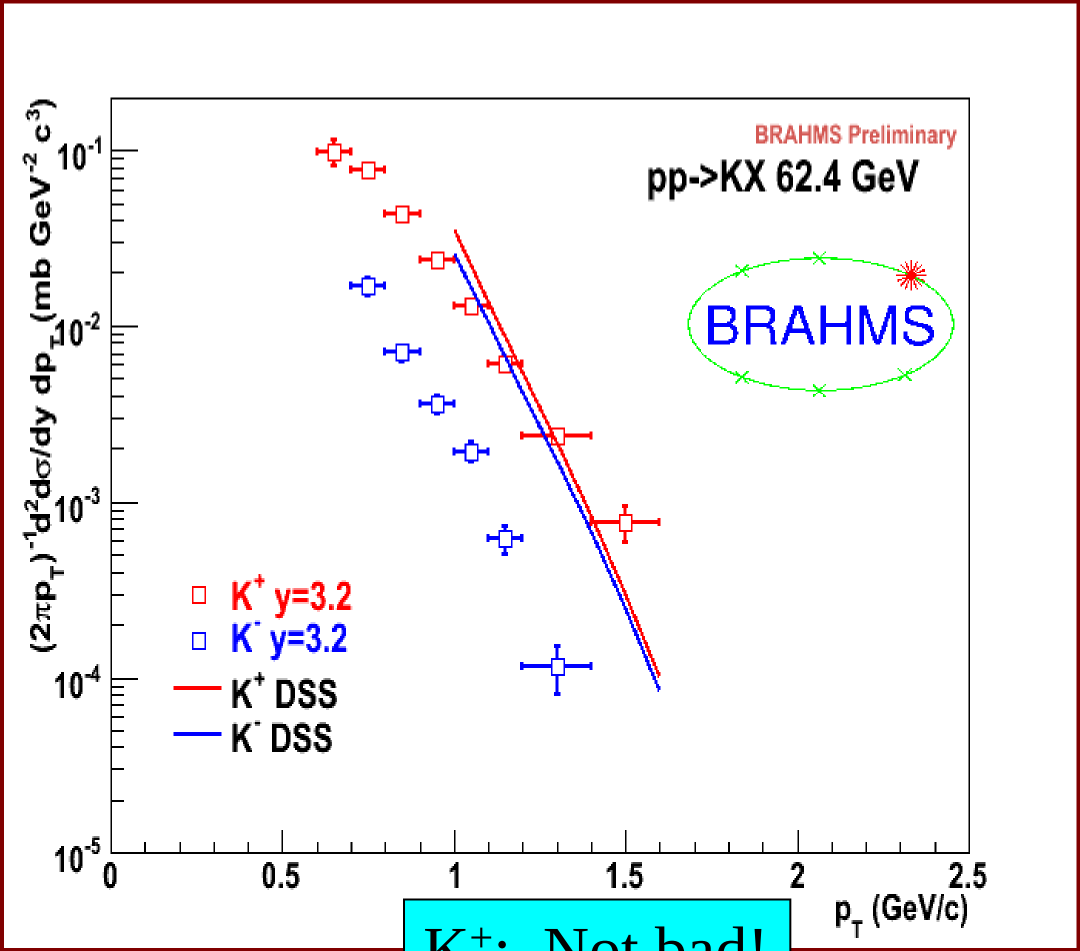
Comparison of NLO pQCD calculations with BRAHMS π data at high rapidity. The calculations are for a scale factor of $\mu=p_T$, KKP (solid) and DSS (dashed) with CTEQ5 and CTEQ6.5.

Surprisingly good description of data, in apparent disagreement with earlier analysis of ISR π^0 data at 53 GeV.

No comparison to NLL yet.

Still not so bad!

$\sqrt{s}$=62.4 GeV
Forward kaons



K^+: Not bad!
K^-: Hmm…

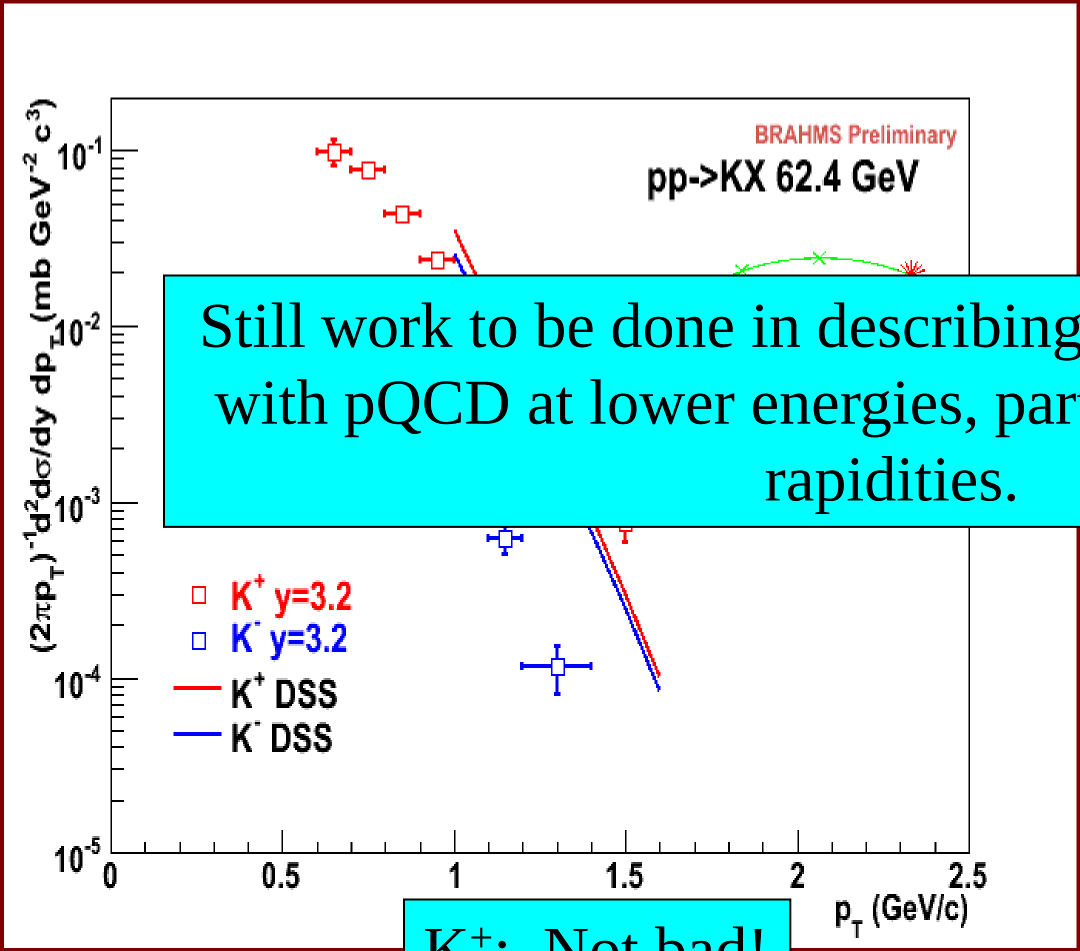
K^- *data* suppressed ~order of magnitude (valence quark effect).

NLO pQCD using recent DSS fragmentation functions (FFs) gives ~same yield for both charges(??).

Related to FFs? pdfs??

No comparison to NLL yet.

$\sqrt{s}$=62.4 GeV
Forward kaons



K^- *data* suppressed ~order of magnitude (valence quark effect).

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~same yield for both charges(??).

Related to FFs? pdfs??

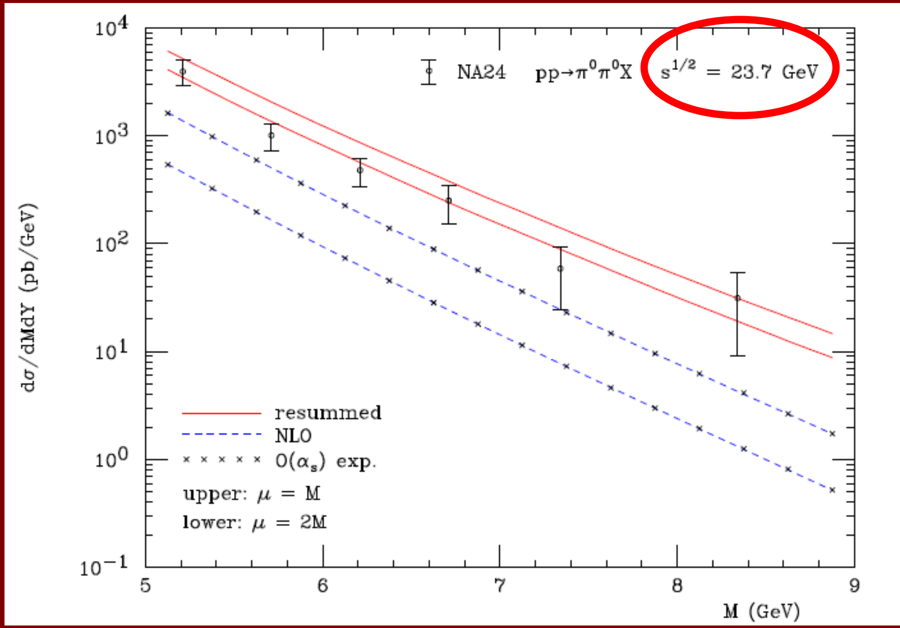
No comparison to NLL yet.

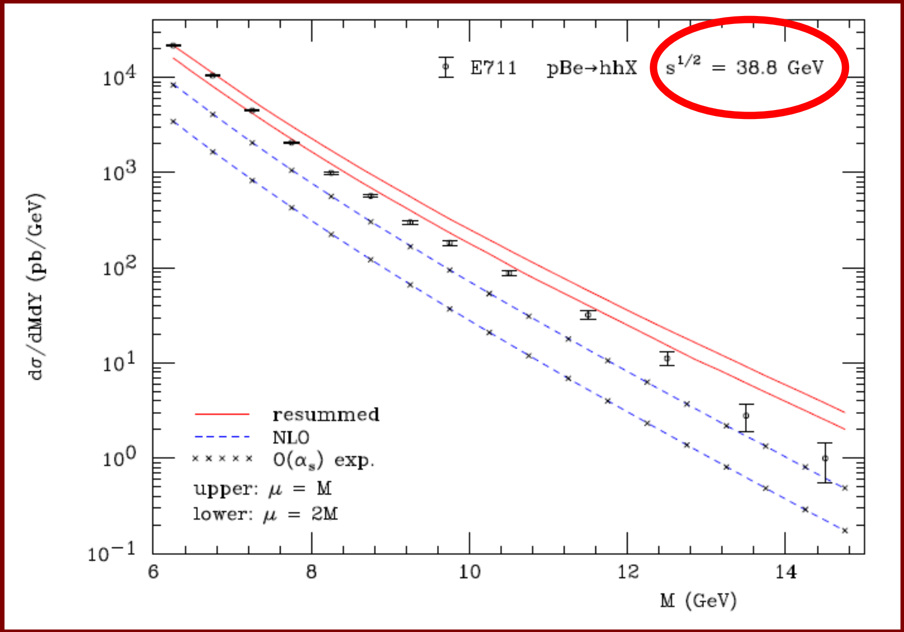
Still work to be done in describing hadronic collisions with pQCD at lower energies, particularly at forward rapidities.

K^+: Not bad!
K^-: Hmm…

Progress in pQCD calculational techniques

23.7 GeV! 38.8 GeV!





One recent example:

Almeida, Sterman, Vogelsang, PRD80, 074016 (2009)

Cross section for di-hadron production vs. invariant mass using threshold resummation (rigorous method for implementing p_T and rapidity cuts on hadrons to match experiment)

11

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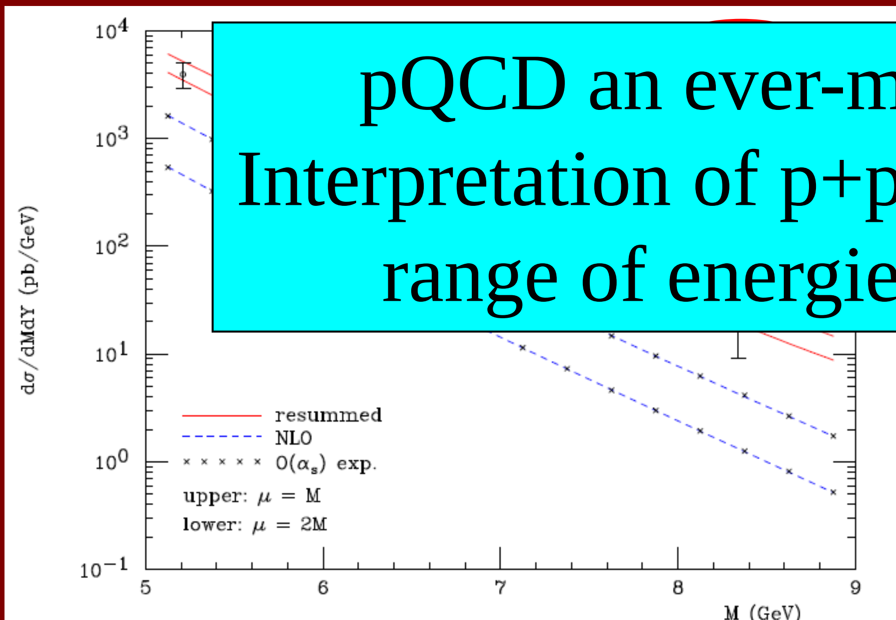

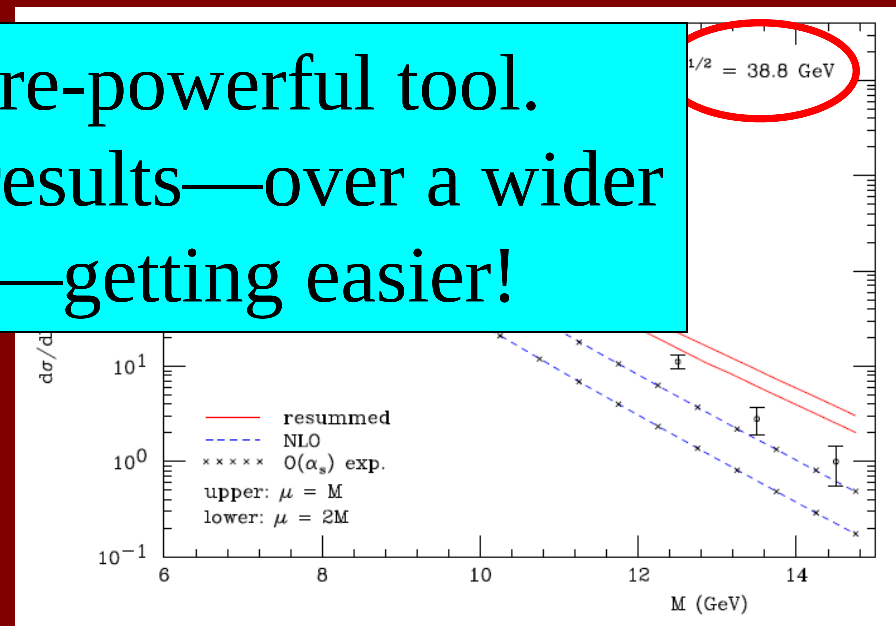

pQCD an ever-more-powerful tool.
Interpretation of p+p results—over a wider range of energies—getting easier!

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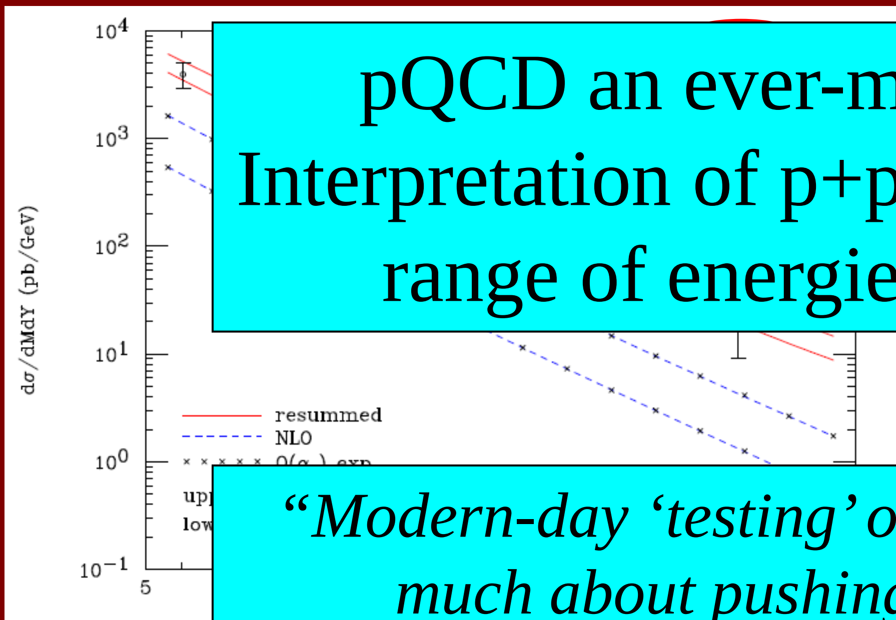

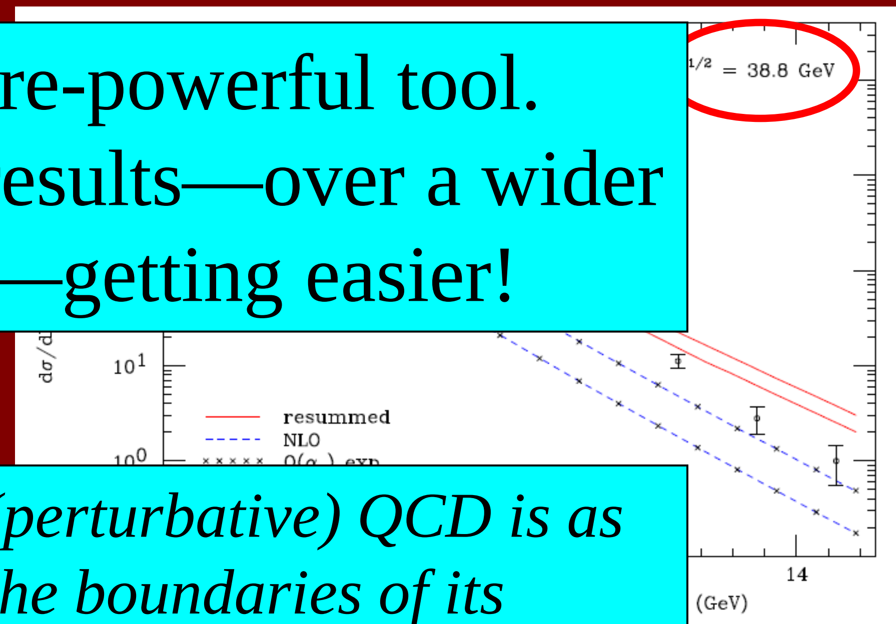

pQCD an ever-more-powerful tool. Interpretation of p+p results—over a wider range of energies—getting easier!

"Modern-day 'testing' of (perturbative) QCD is as much about pushing the boundaries of its applicability as about the verification that QCD is the correct theory of hadronic physics."
– G. Salam, hep-ph/0207147 (DIS2002 proceedings)

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Cross d

resummation (rigorous method for implementing p_T and rapidity cuts on hadrons to match experiment)

13

PHENIX detector

- 2 central spectrometers
  - Track charged particles and detect electromagnetic processes

$|\eta| < 0.35$

$90^\circ + 90^\circ$ azimuth

- 2 forward muon spectrometers
  - Identify and track muons

$1.2 < |\eta| < 2.4$

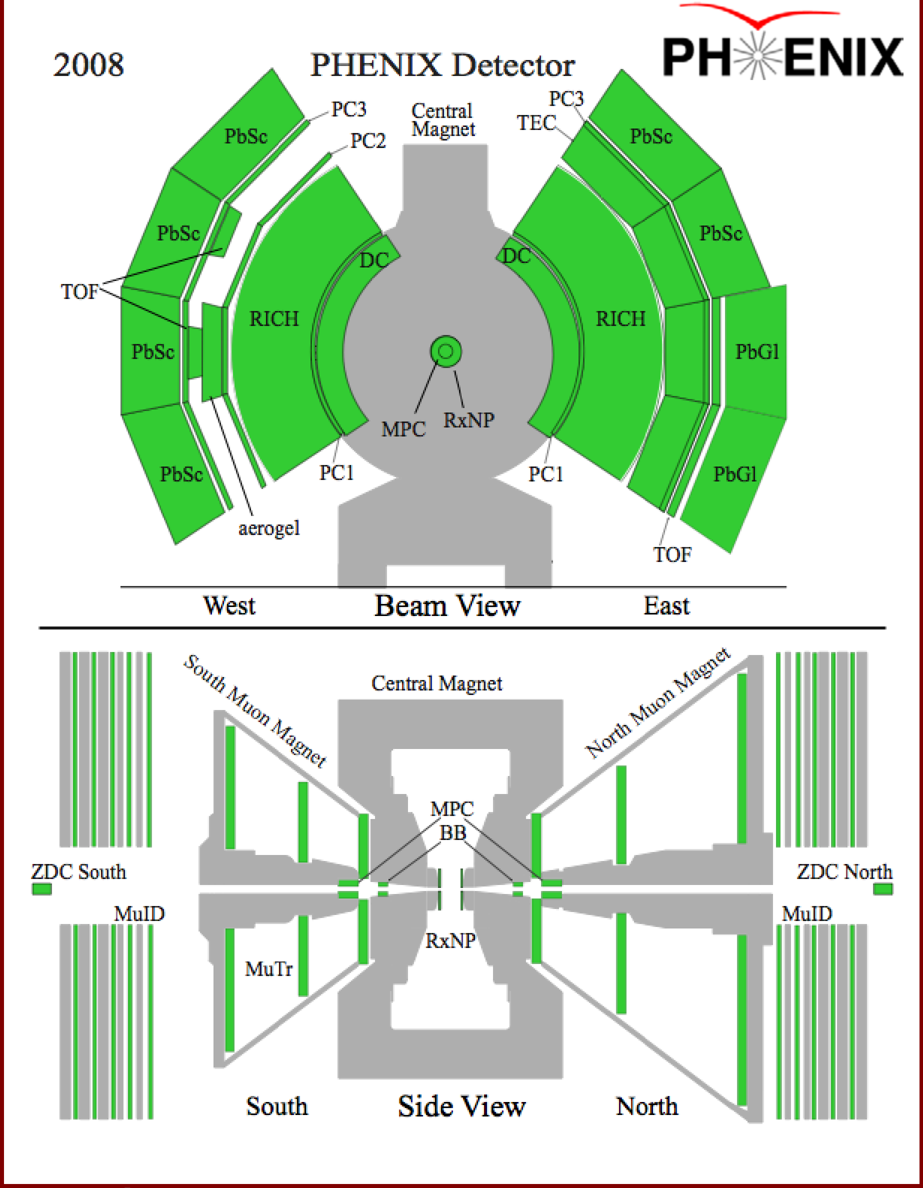
2π azimuth

- 2 forward EM calorimeters (as of 2007)
  - Measure forward pions, etas

$3.1 < |\eta| < 3.7$

2π azimuth

- Luminosity counters
  - Beam-Beam Counter (BBC)
  - Zero-Degree Calorimeter (ZDC)



PHENIX detector

Philosophy:

High rate capability to measure rare probes, fine granularity calorimetry, limited acceptance.

- Track charged particles and detect electromagnetic processes

$|\eta| < 0.35$

$90^\circ + 90^\circ$ azimuth

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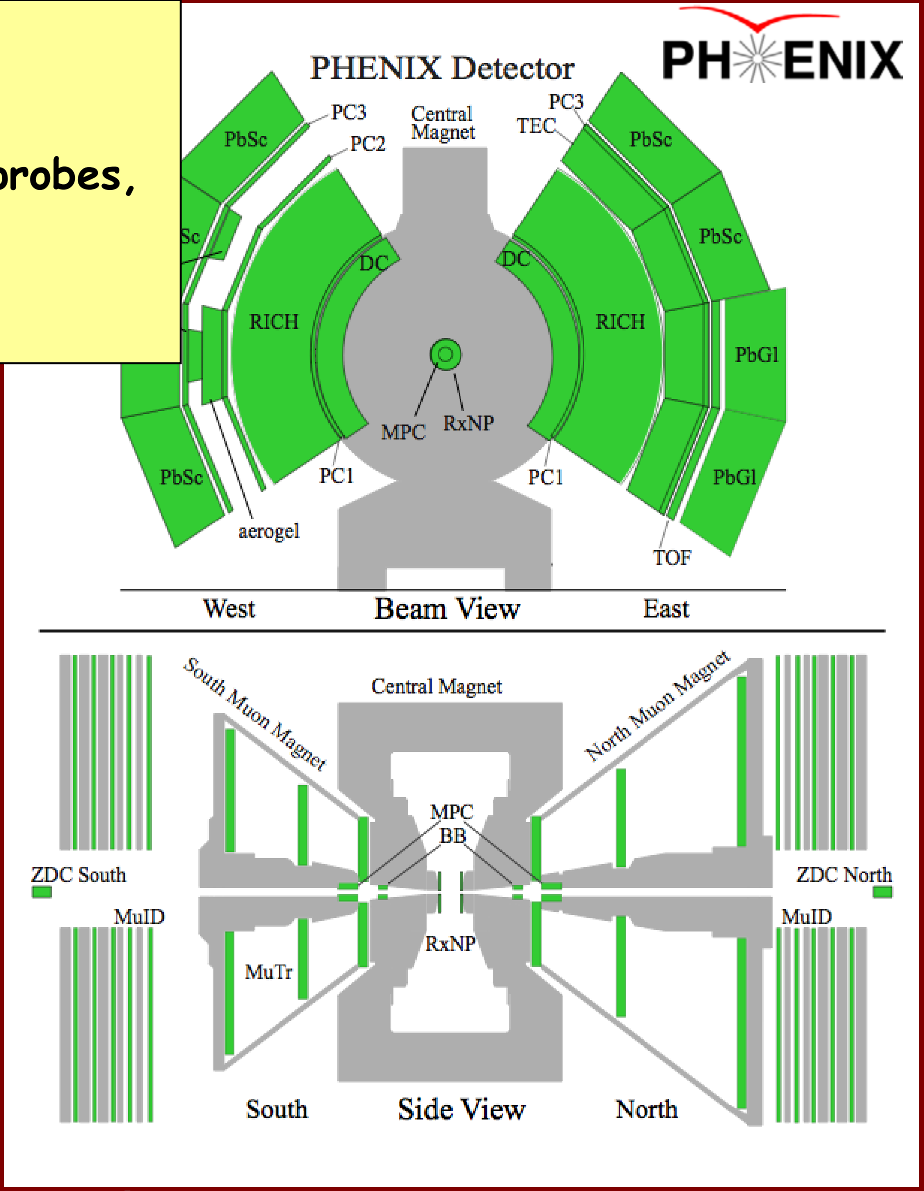
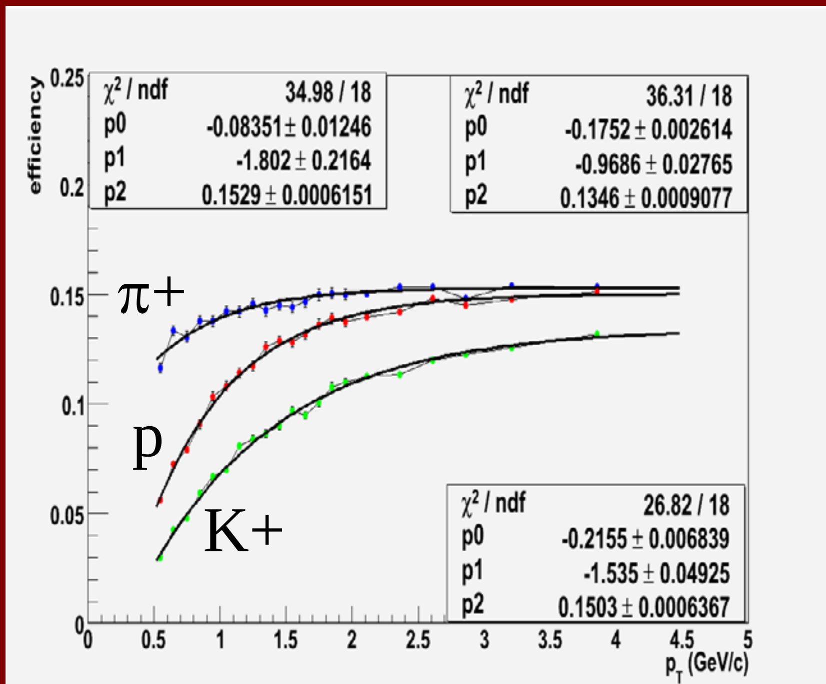


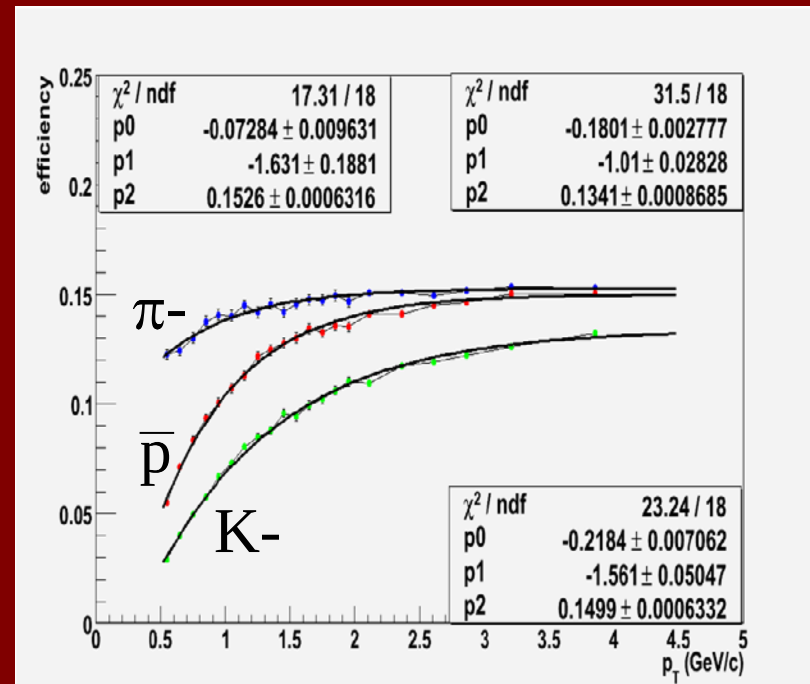
Measuring midrapidity charged hadrons at PHENIX

- Two-week p+p run at sqrt(s)=62.4 GeV in 2006
- Analyzed 11.1 nb^{-1} (214M events)
- Reconstruct tracks using Drift Chamber and Pad Chambers
- RICH veto to eliminate electrons
- Coincidence in two Beam-Beam Counters required for minimum-bias event
  - Luminosity counters

$$E\frac{d^3\sigma}{dp^3} = \frac{\sigma_{BBC}}{N_{MB}}\frac{1}{2\pi p_T}\frac{N_{yield}(p_T)}{dydp_T}R_{smear}(p_T)C^{trig}_{bias}(p_T)C^{acc}_{eff}(p_T),$$

Particle-species dependent efficiency corrections

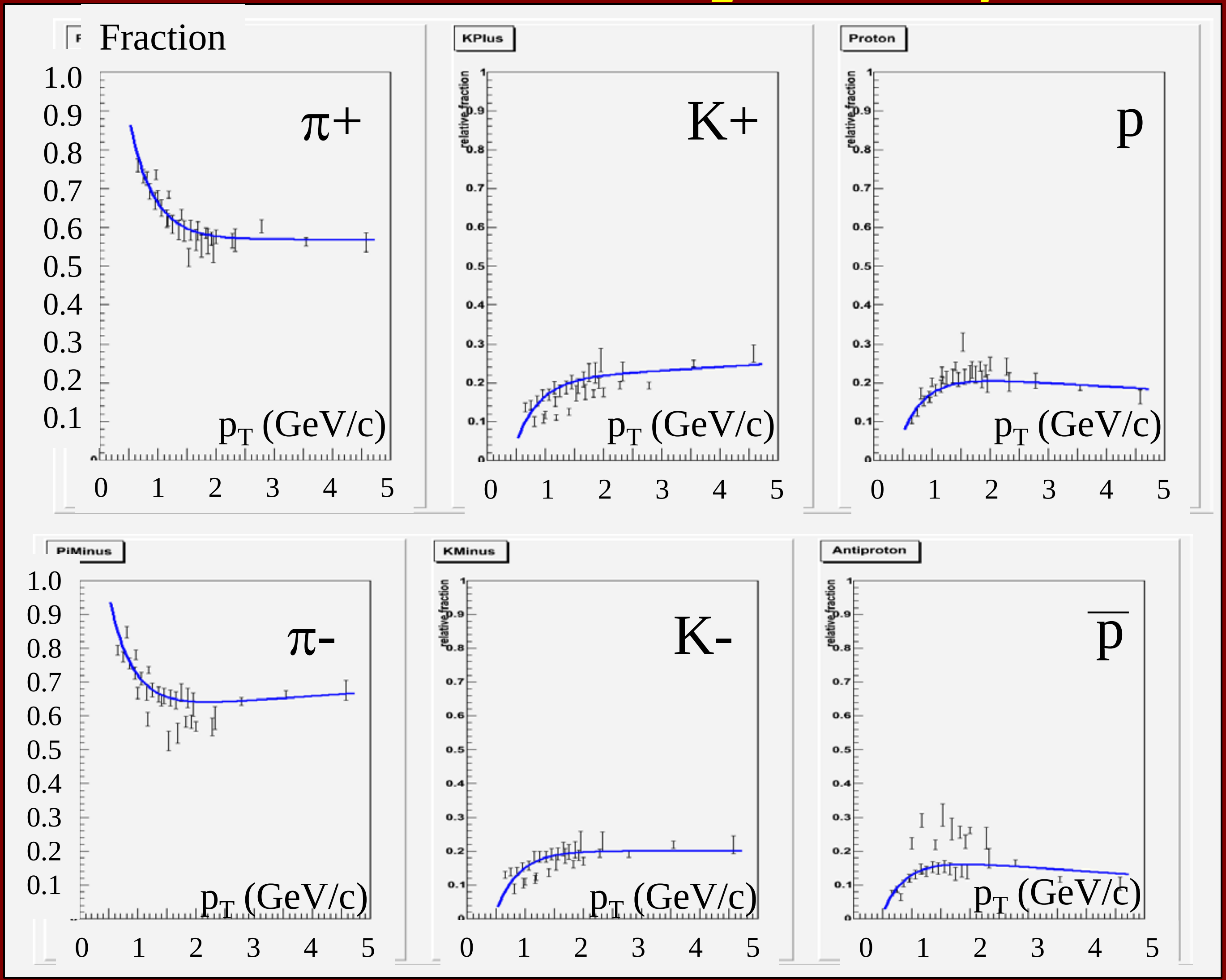




F(x) = [0]*exp([1] *x) + [2]

- Use Monte Carlo to generate single-particle events over 2π in azimuth and one unit of rapidity
- Run through full GEANT detector simulation, matching dead channel maps and fiducial cuts to experiment

Particle species fractions

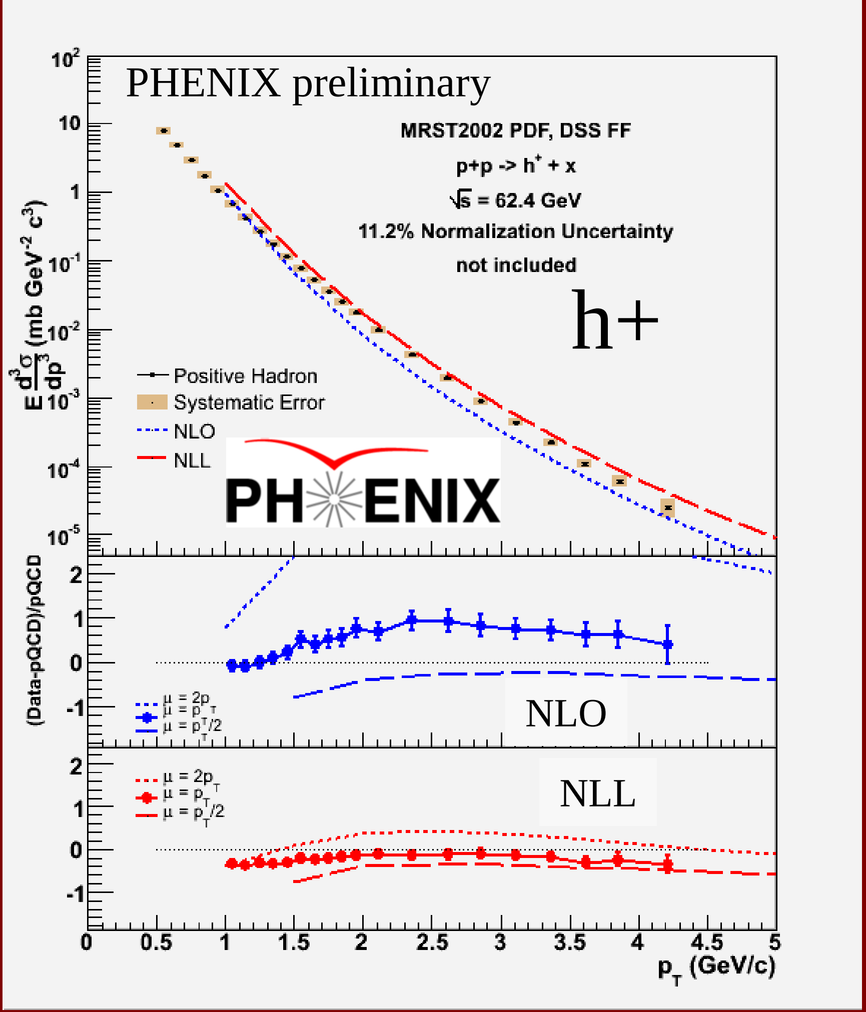


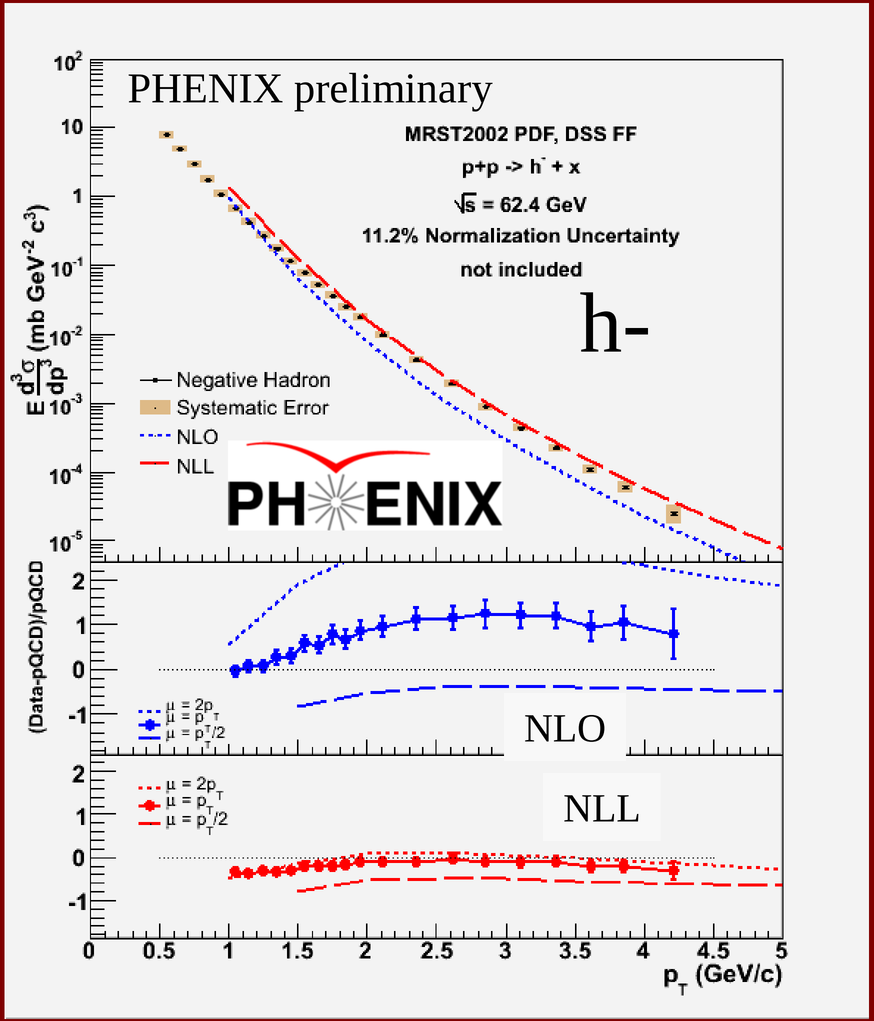
- For non-identified charged hadron analysis, need particle species fractions to weight efficiencies
- Obtain from fits to identified data fractions at same energy from PHENIX and ISR
- Estimate systematic uncertainty using fractions from one data set only

F(x) = [0]exp([1] *x) + [2] + [3]*x

(Fits constrained to sum to1 across all p_T)

Midrapidity charged hadron production at 62.4 GeV: Results





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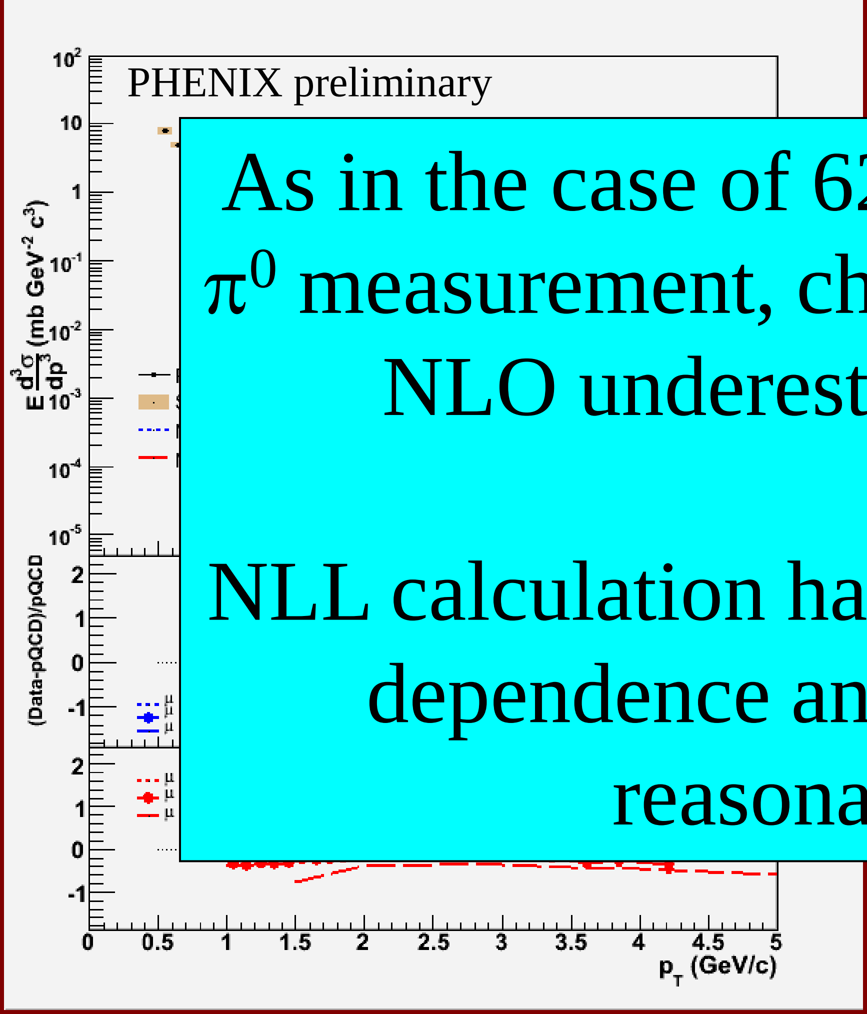
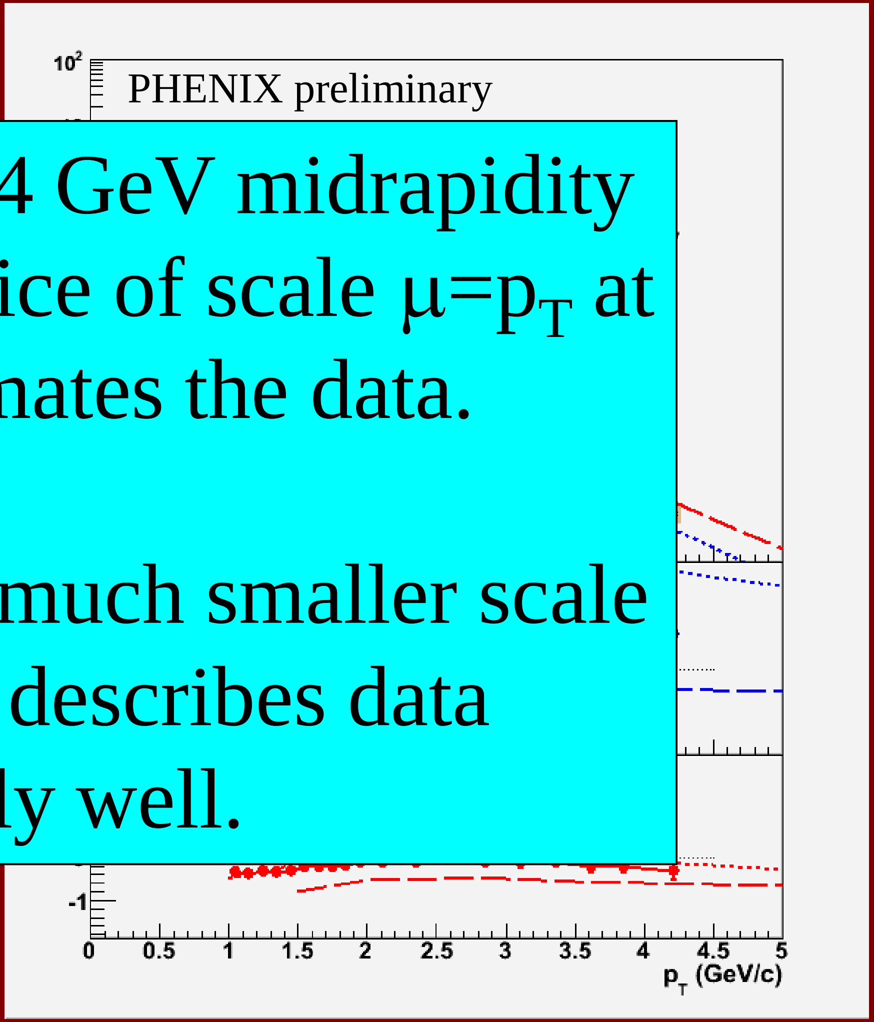




As in the case of 62.4 GeV midrapidity π^0 measurement, choice of scale $\mu=p_T$ at NLO underestimates the data.

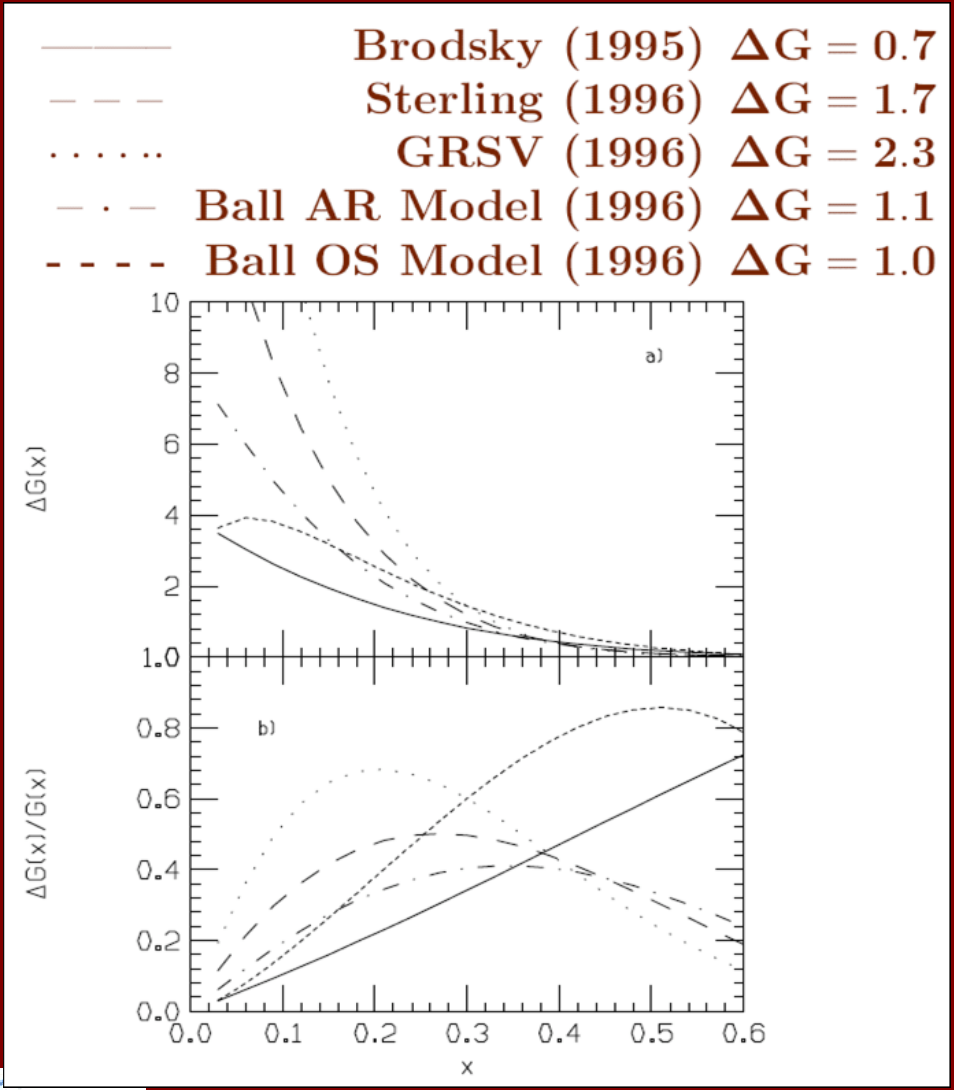
NLL calculation has much smaller scale dependence and describes data reasonably well.

Systematic uncertainties on cross sections

- 1 – 5% from PID fraction
- 0.6 – 5% from background fraction
- 0.5 – 1.5% from correction factor for smearing
- 2.2% from MC/data scale factor
- **11 – 24% from ‘acceptance + efficiency’ correction values**

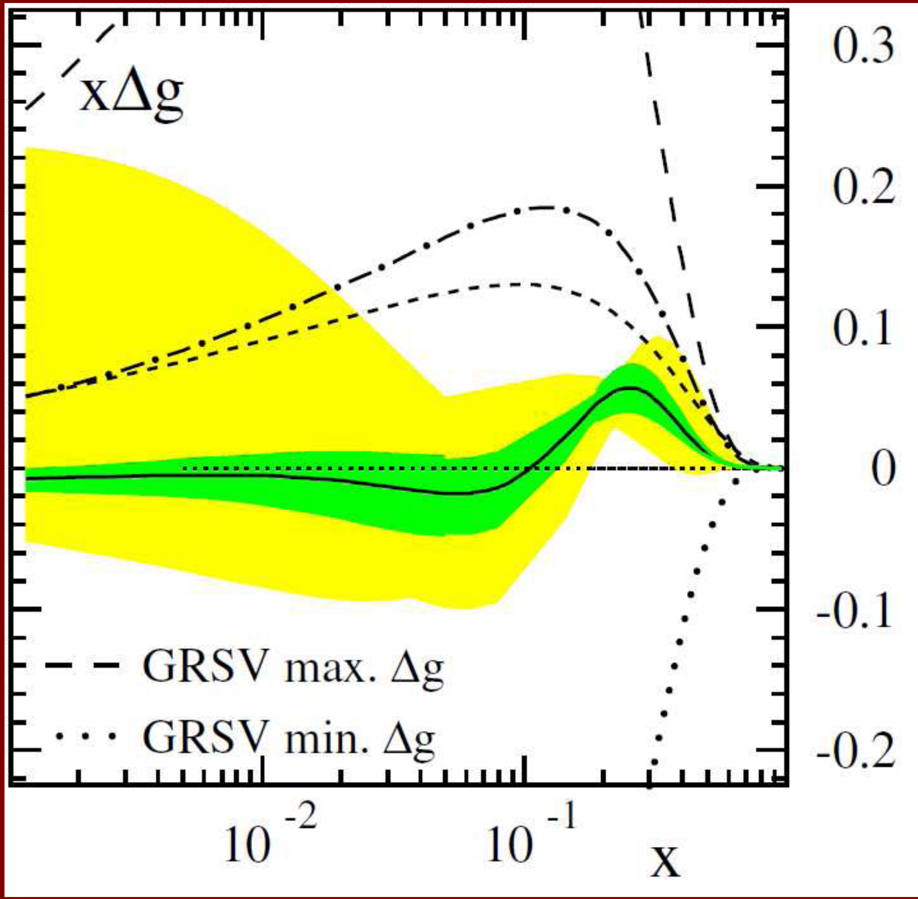
- **11.2% overall normalization uncertainty**

The quest for ΔG, the gluon spin contribution to the spin of the proton



- With experimental evidence already indicating that only about 30% of the proton's spin is due to the spin of the quarks, in the mid-1990s, predictions for ΔG at x=0.1 ranged from 2 to 10(!)

The quest for ΔG, the gluon spin contribution to the spin of the proton



de Florian et al., PRL101, 072001 (2008)

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- Global NLO pQCD fit by DSSV in 2008 including RHIC data at 200 and 62.4 GeV results in best fit with ΔG<0.5 at x=0.1

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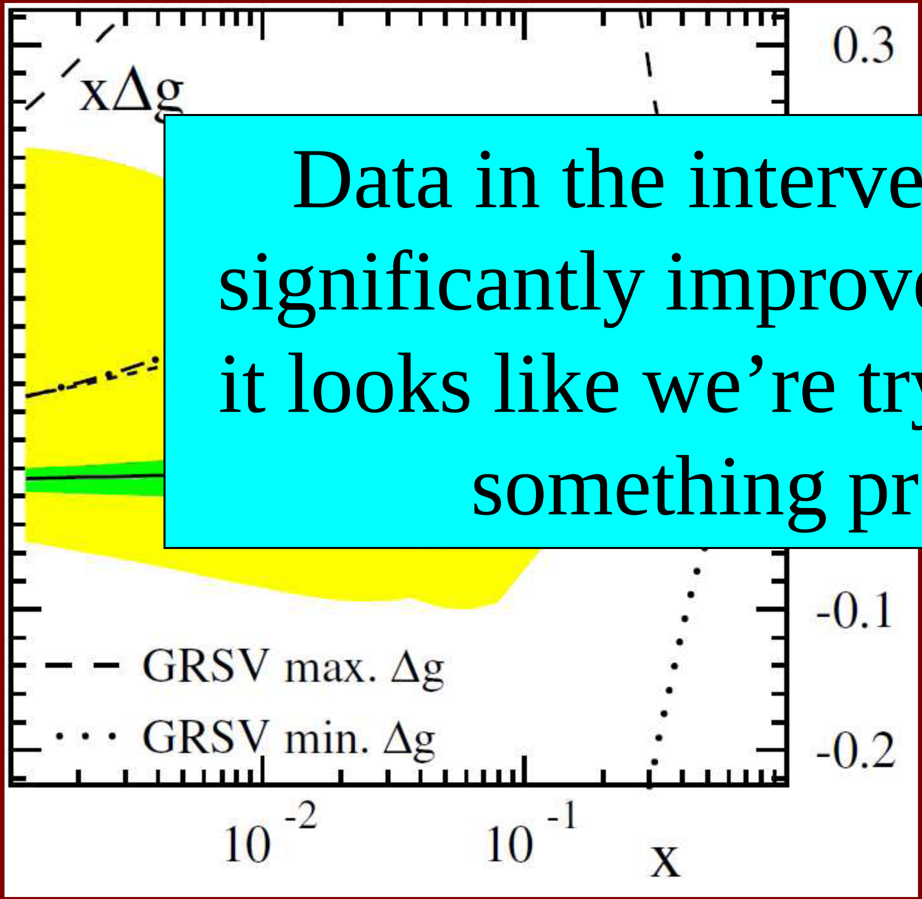

de Florian et al., PRL101, 072001 (2008)

Data in the intervening years have significantly improved constraints, but it looks like we're trying to hunt down something pretty small!

- With experimental evidence … only … on's … of the … 0s, … x=0.1 ranged from 2 to 10(!)
- Global NLO pQCD fit by DSSV in 2008 including RHIC data at 200 and 62.4 GeV results in best fit with ΔG<0.5 at x=0.1

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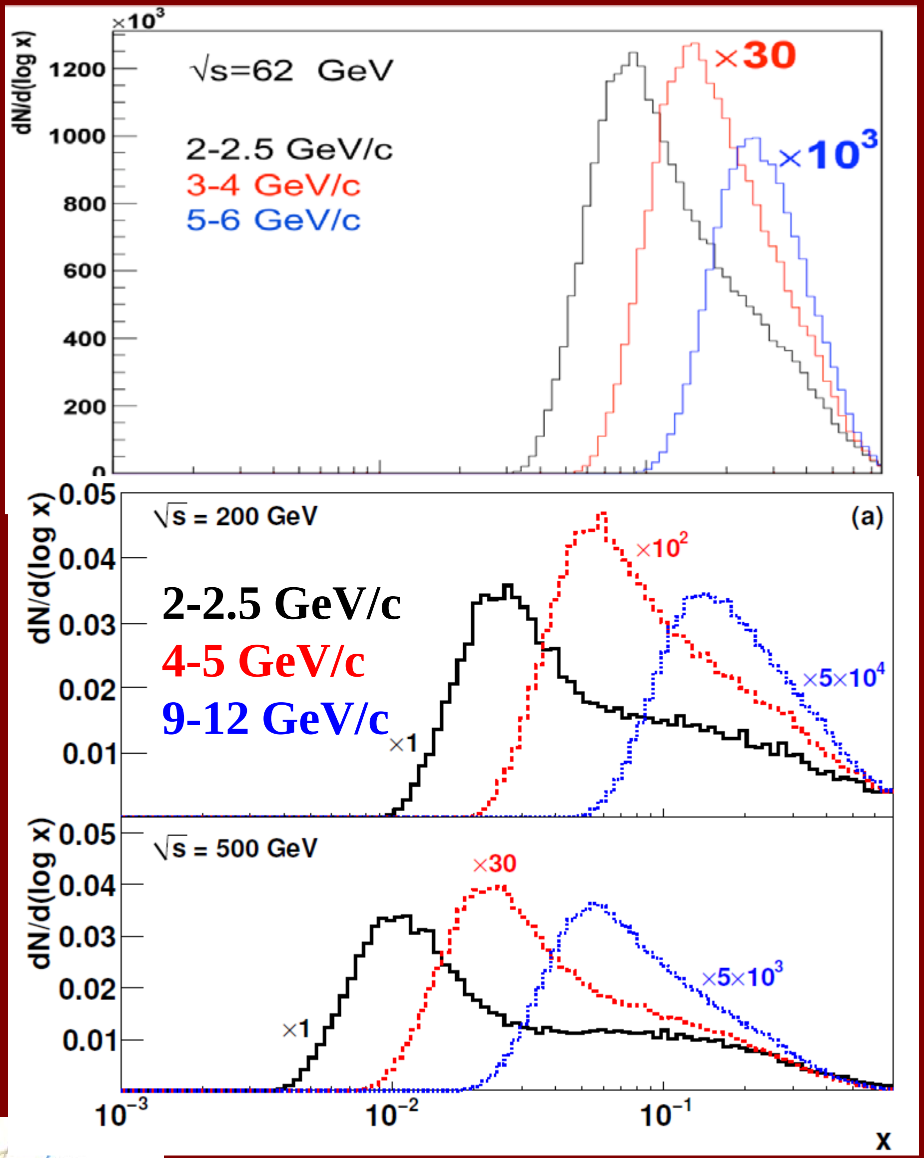
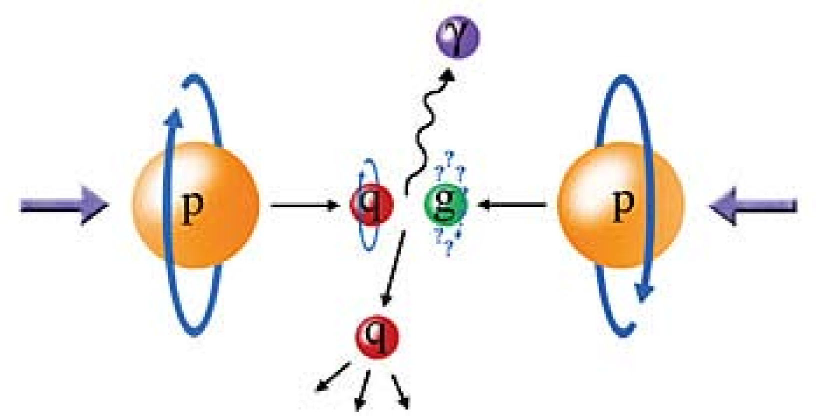
(Gradually) Mapping out Δg(x)



- In p+p collisions, parton momentum fraction x correlated with p_T of produced particle in a hard-scattering event
- RHIC a very flexible machine—sqrt(s) for p+p collisions 50-500 GeV
- Running at different energies samples from different x ranges

Probing the Helicity Structure of the Nucleon with p+p Collisions



$$A_{LL} = \frac{\Delta\sigma}{\sigma} = \frac{1}{|P_1 P_2|} \frac{N_{++}/L_{++} - N_{+-}/L_{+-}}{N_{++}/L_{++} + N_{+-}/L_{+-}}$$

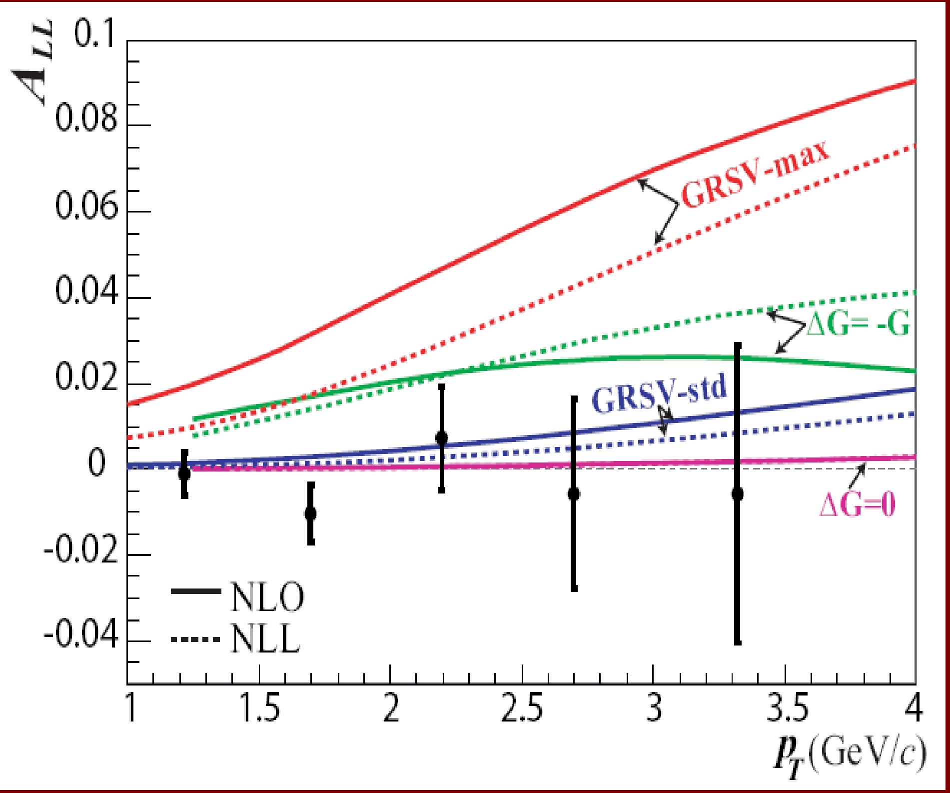
Study difference in particle production rates for same-helicity vs. opposite-helicity proton collisions

$$\Delta\sigma(pp \to \pi^0 X) \propto \Delta q(x_1) \otimes \Delta g(x_2) \otimes \Delta\hat{\sigma}^{qg\to qg}(\hat{s}) \otimes D_q^{\pi^0}(z)$$

(mainly) DIS ? pQCD (mainly) e+e-

Leading-order access to gluons → ΔG

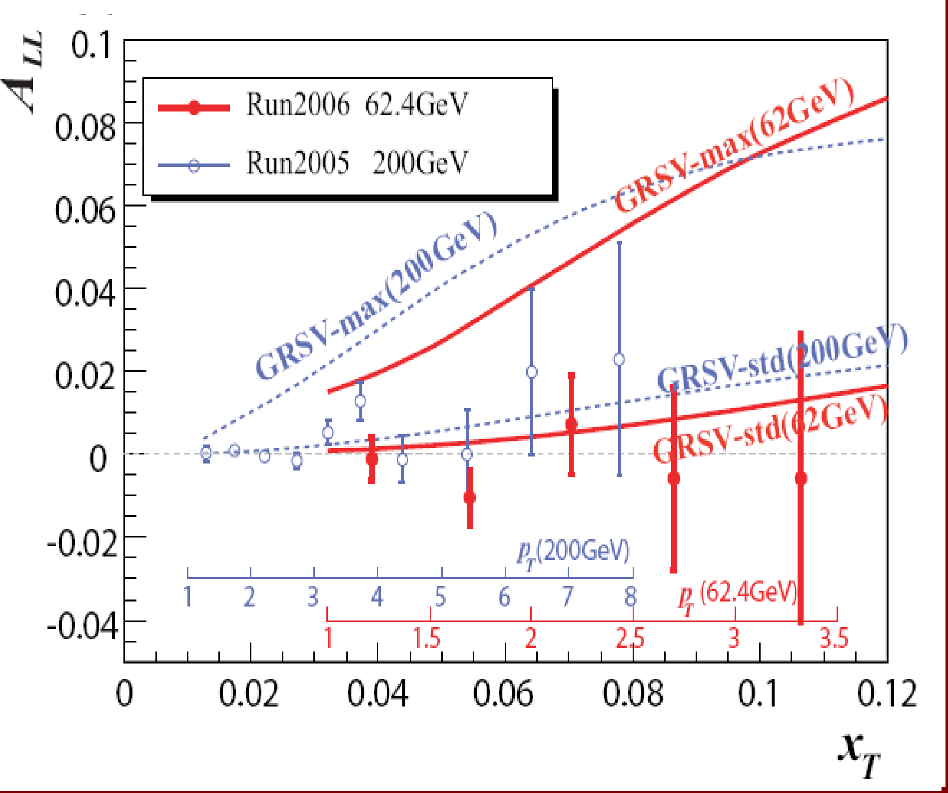
Neutral Pion A_{LL} at 62.4 GeV



PRD79, 012003 (2009)

Neutral Pion A_{LL} at 62.4 GeV

$$x_T = \frac{2p_T}{\sqrt{s}}$$



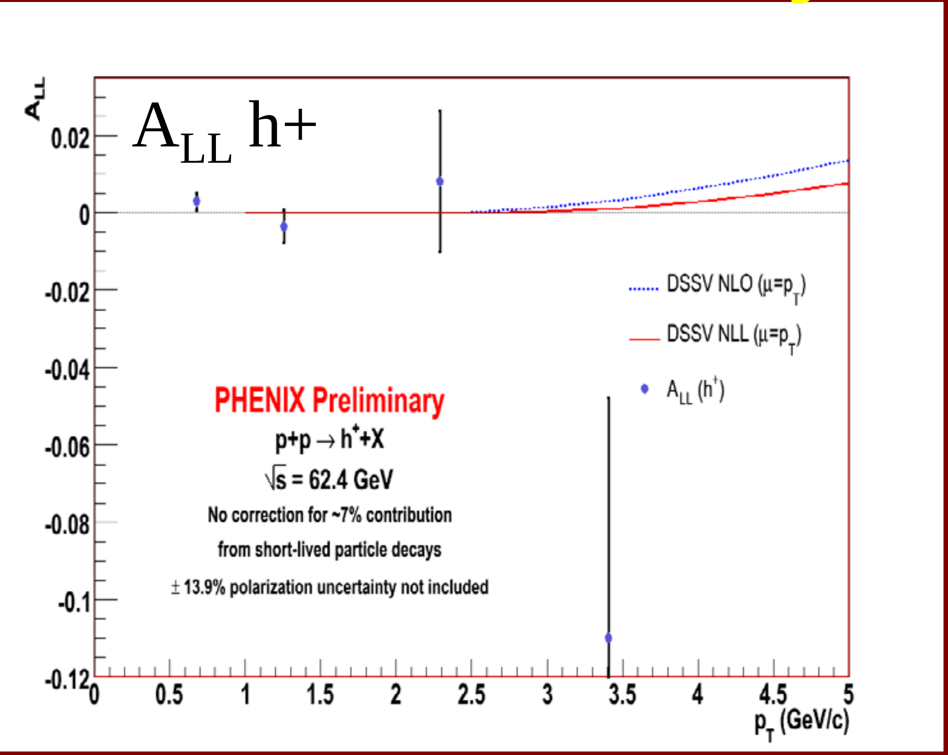
Converting to x_T, can see significance of 62.4 GeV measurement (0.08 pb^{-1}) compared to published data from 2005 at 200 GeV (3.4 pb^{-1}).

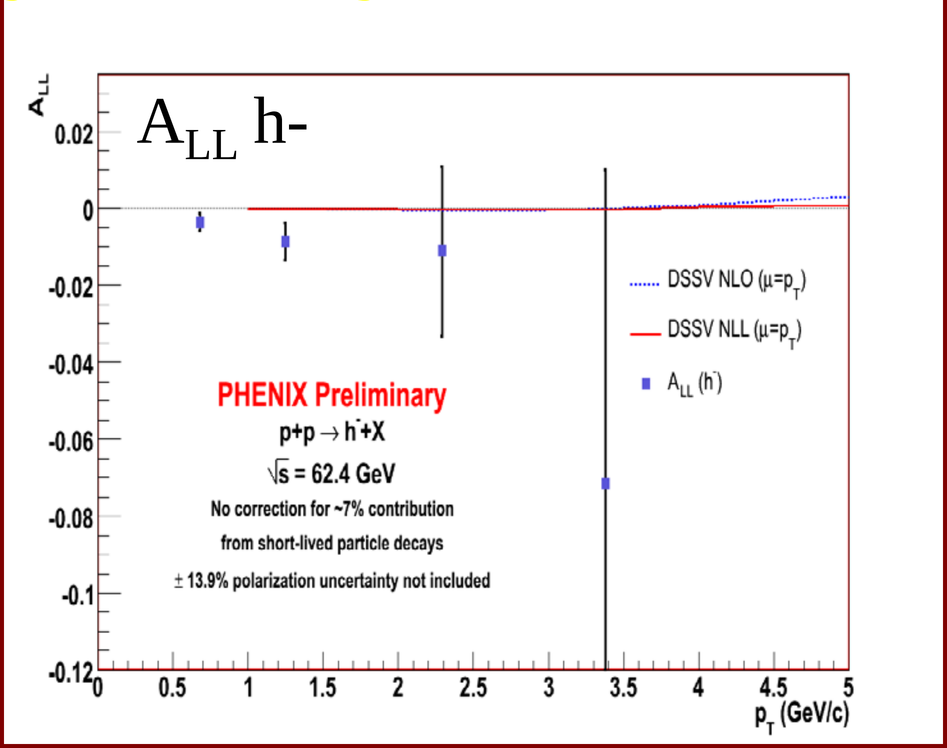
$$0.02 < x_{gluon} < 0.3 \quad (\sqrt{s} = 200\,\text{GeV})$$

$$0.06 < x_{gluon} < 0.4 \quad (\sqrt{s} = 62.4\,\text{GeV})$$

PRD79, 012003 (2009)

Double-helicity asymmetry: Results





Average polarization: 0.48
13.9% scale uncertainty on product of beam polarizations.
Uncertainty on A_{LL} due to relative luminosity uncertainty: 1.4×10^{-3}
Theoretical curves for NLO and NLL obtained by summing species-dependent predictions weighted by detection efficiencies.

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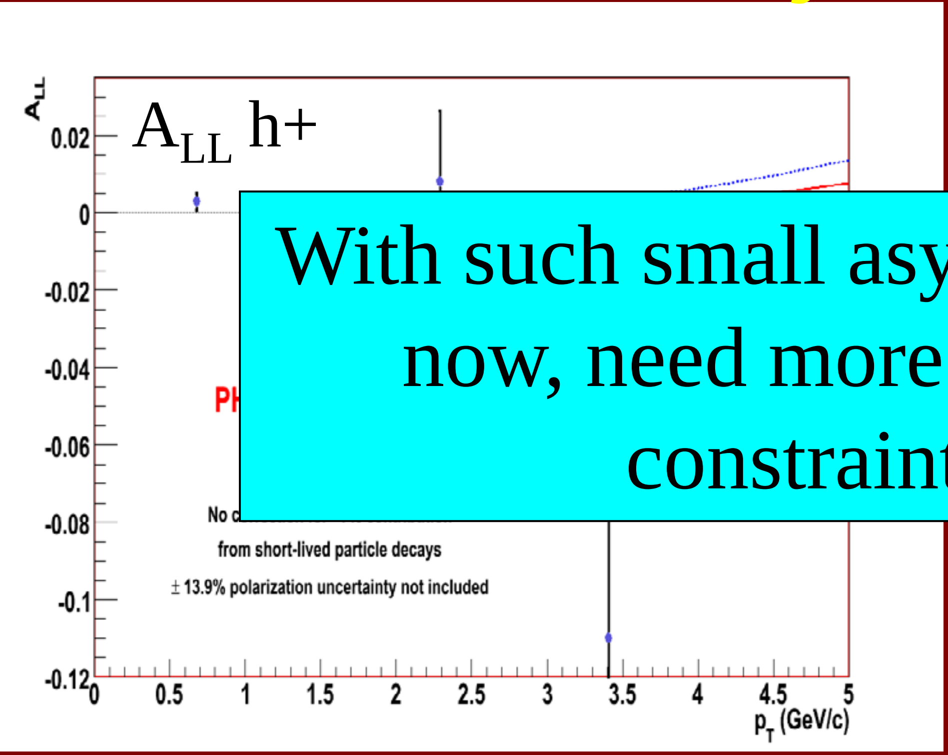

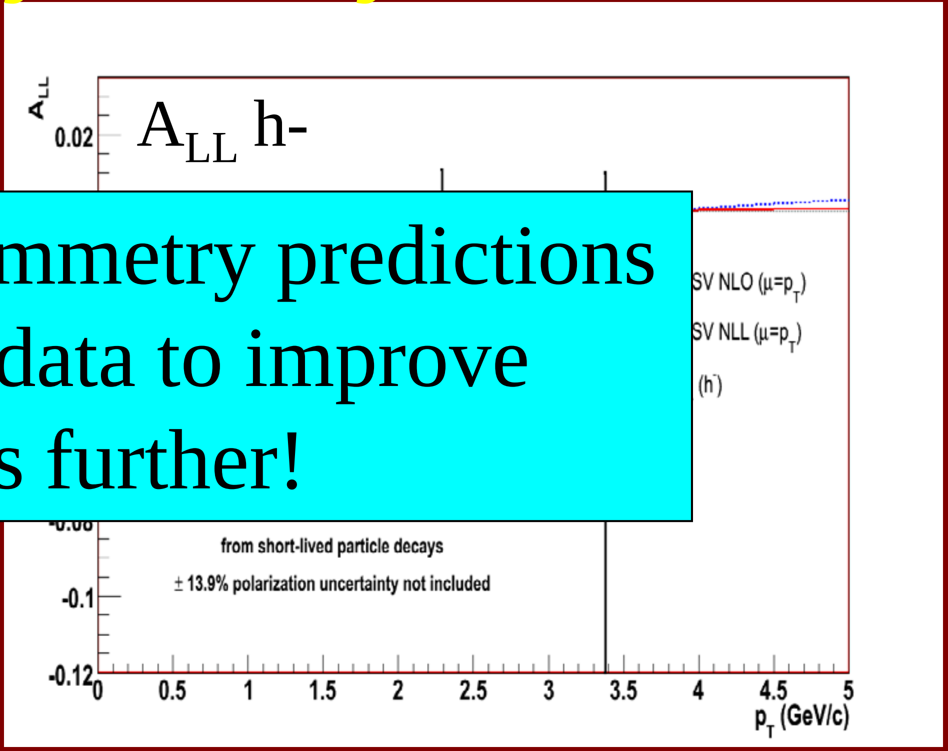

With such small asymmetry predictions now, need more data to improve constraints further!

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13.9% scale uncertainty on product of beam polarizations.

Uncertainty on A_{LL} due to relative luminosity uncertainty: $1.4\text{x}10^{-3}$

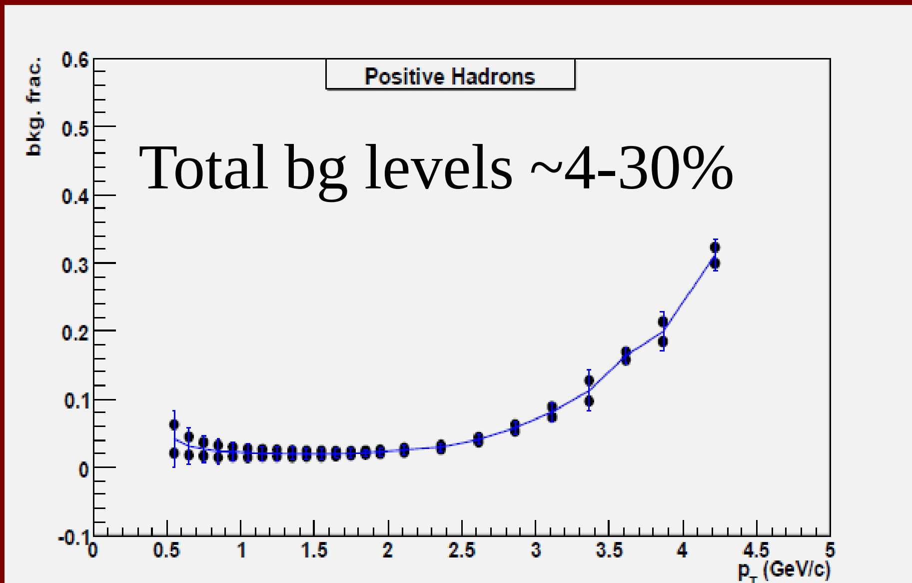
Theoretical curves for NLO and NLL obtained by summing species-dependent predictions weighted by detection efficiencies.

Summary

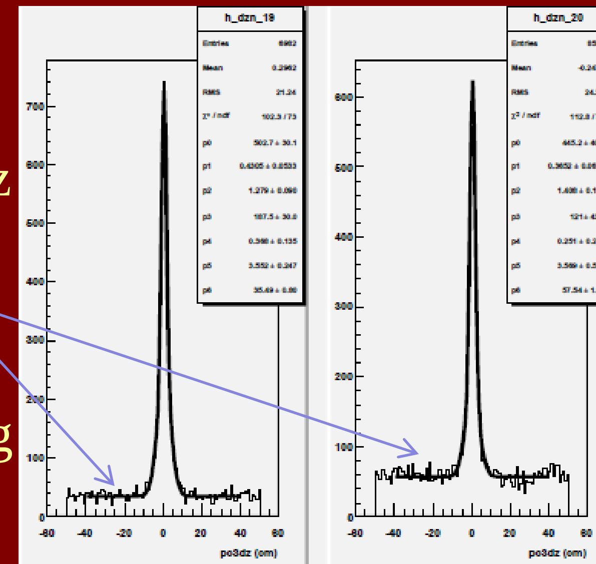
- Cross section and double-helicity asymmetry for midrapidity charged hadrons at sqrt(s)=62.4 GeV have been measured by PHENIX
- Comparison of cross section data to pQCD calculations can provide information on applicability of different calculational techniques
  – NLL resummation relevant for midrapidity at 62.4 GeV?
- Measurement of double-helicity asymmetries at RHIC for processes calculable in pQCD over a range of energies and for a variety of observables can help constrain $\Delta g(x)$

Backup

Background estimation



~Flat tails in z distribution around projected hit—due to bg



Matching in z to PC3 for two high-p_T bins

Most significant background from decays in flight

• PHENIX did not have a vertex detector in 2006

-Tracks assumed to originate at the event vertex

- Project track stubs measured in Drift Chamber and PC1 to outer detectors and look for matching hit in phi, z

• Drift Chamber outside of magnetic field

→ Decays that happen right in front of the Drift Chamber bend very little and get (mis)reconstructed with high p_T --use matching distributions to estimate

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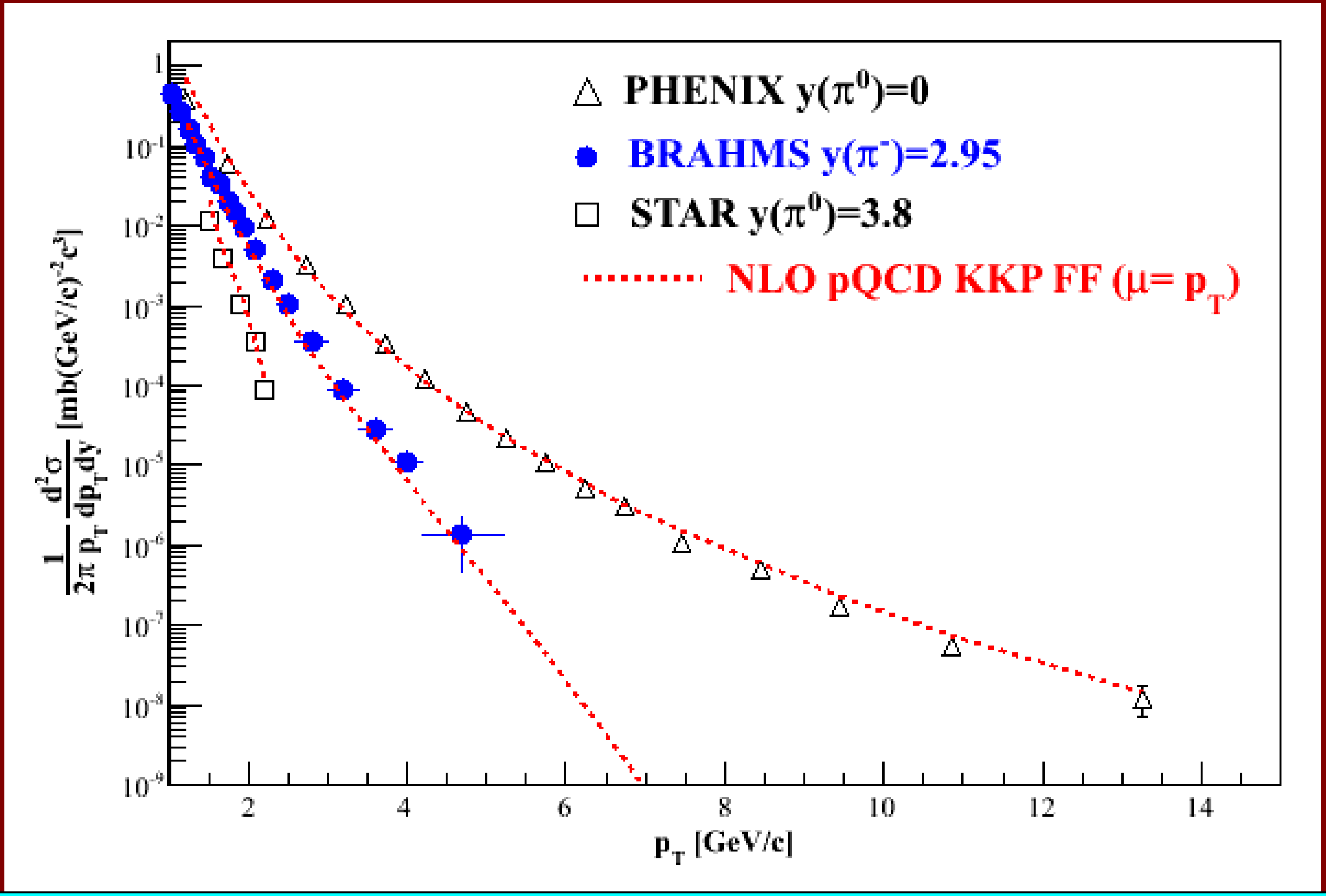
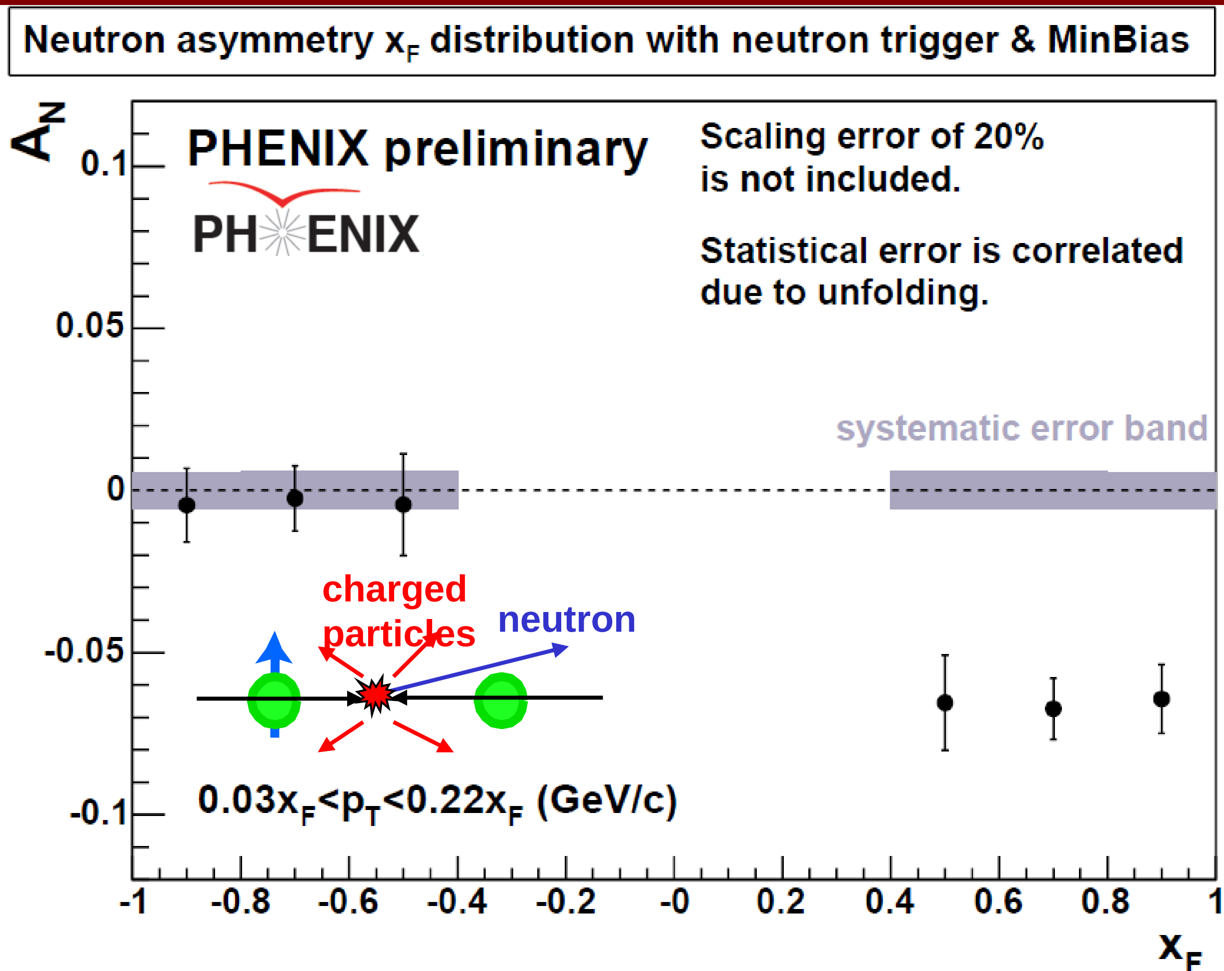
Polarization-averaged cross sections at √s=200 GeV



Good description at 200 GeV over all rapidities down to p_T of 1-2 GeV/c.

Forward neutrons at $\sqrt{s}$=200 GeV at PHENIX

Large negative SSA observed for x_F>0, enhanced by requiring concidence with forward charged particles ("MinBias" trigger).
No x_F dependence seen.



Mean p_T
(Estimated by simulation assuming ISR p_T dist.)

$0.4<|x_F|<0.6$ 0.088 GeV/c
$0.6<|x_F|<0.8$ 0.118 GeV/c
$0.8<|x_F|<1.0$ 0.144 GeV/c

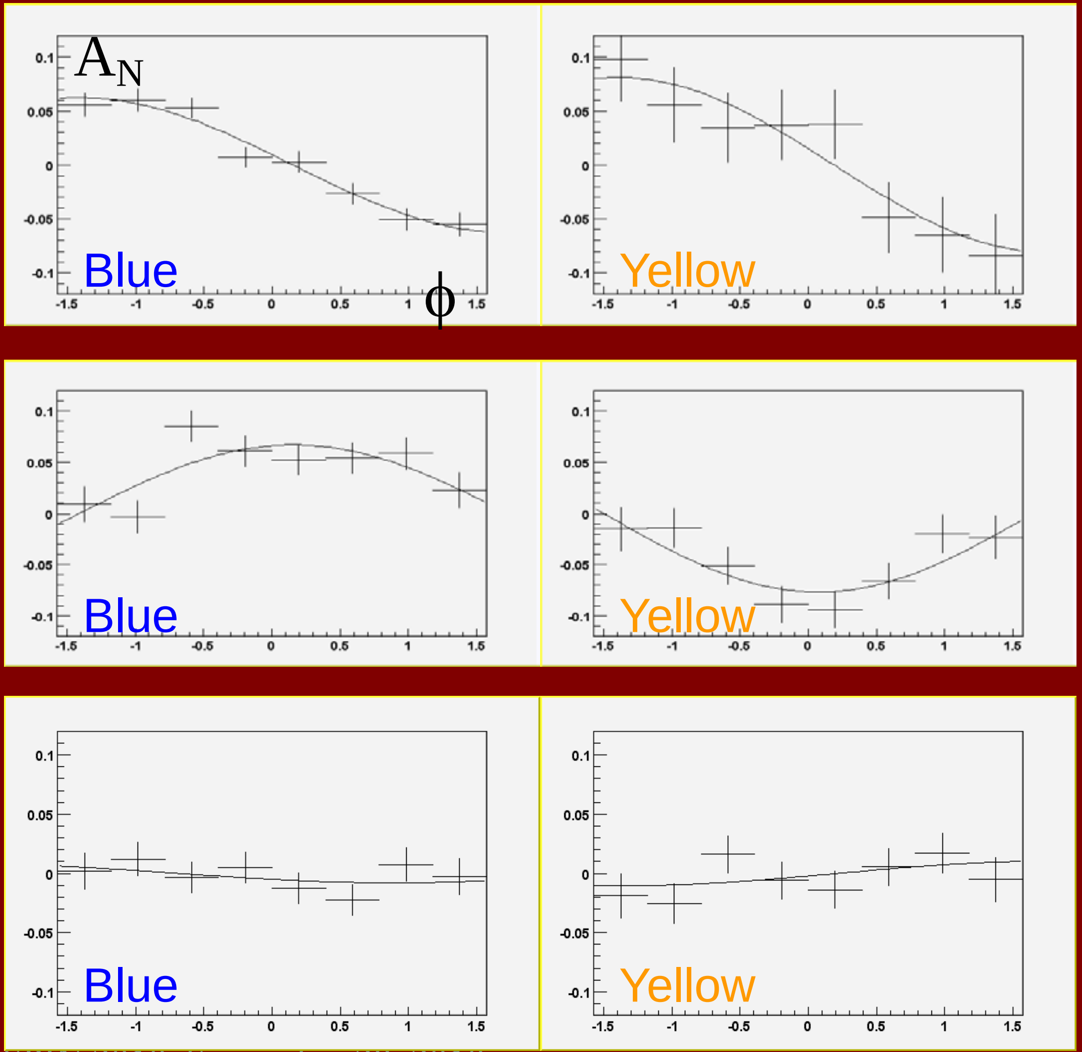
preliminary	A_N
Without MinBias	-6.6 ±0.6 %
With MinBias	-8.3 ±0.4 %

Neutron SSA for local polarimetry

Spin Rotators OFF
Vertical polarization

Spin Rotators ON
Radial polarization

Spin Rotators ON
Longitudinal polarization



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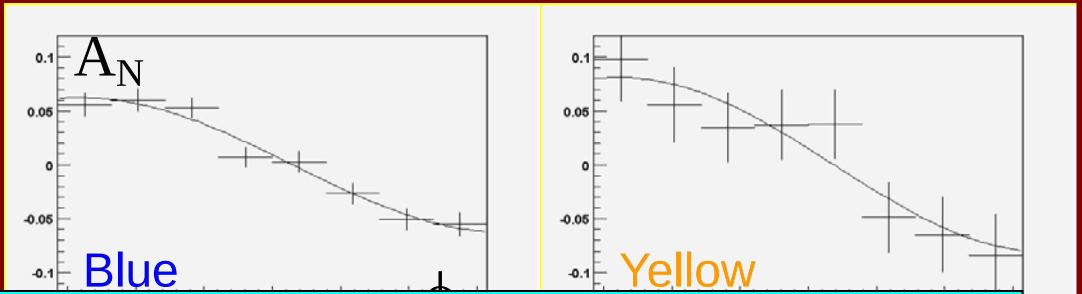
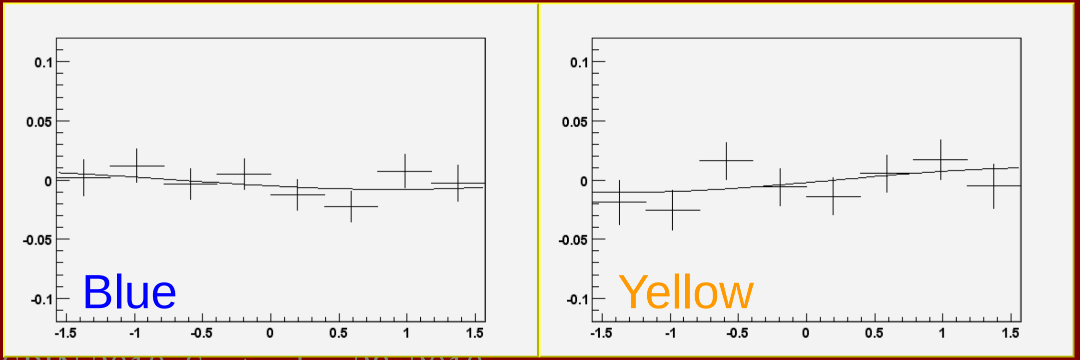
Neutron SSA for local polarimetry

Spin Rotators OFF
Vertical polarization



Allows measurement of any remaining component in an undesired direction

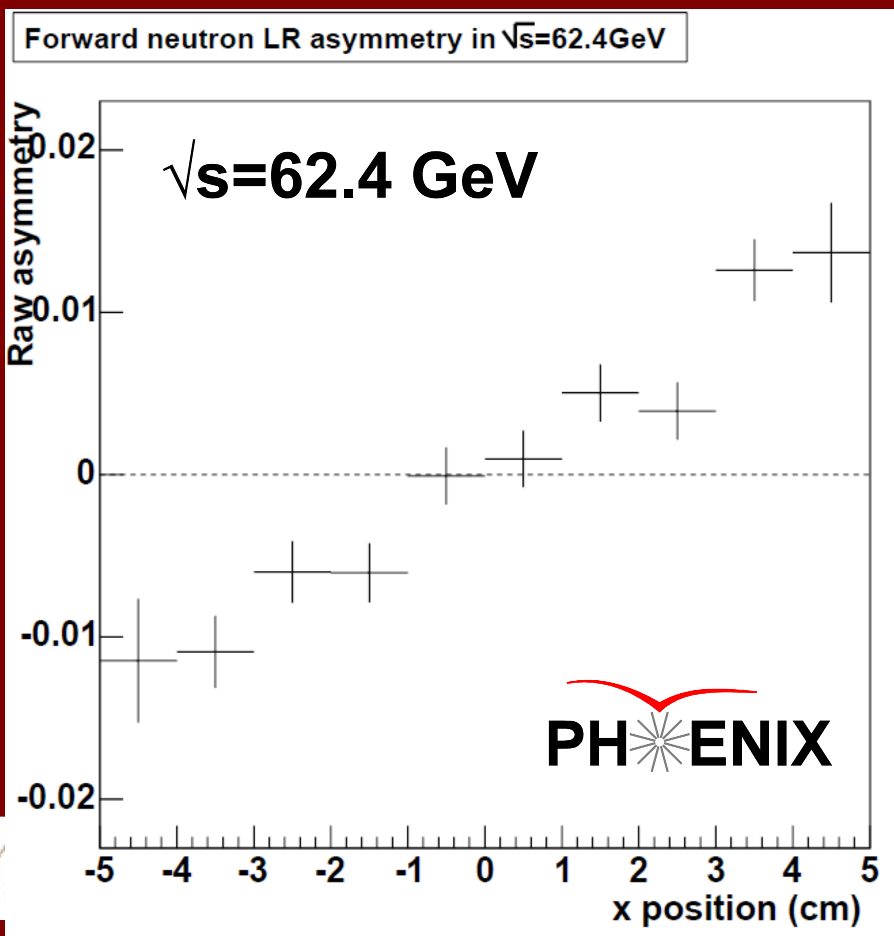
Spin Rotators ON
Longitudinal polarization

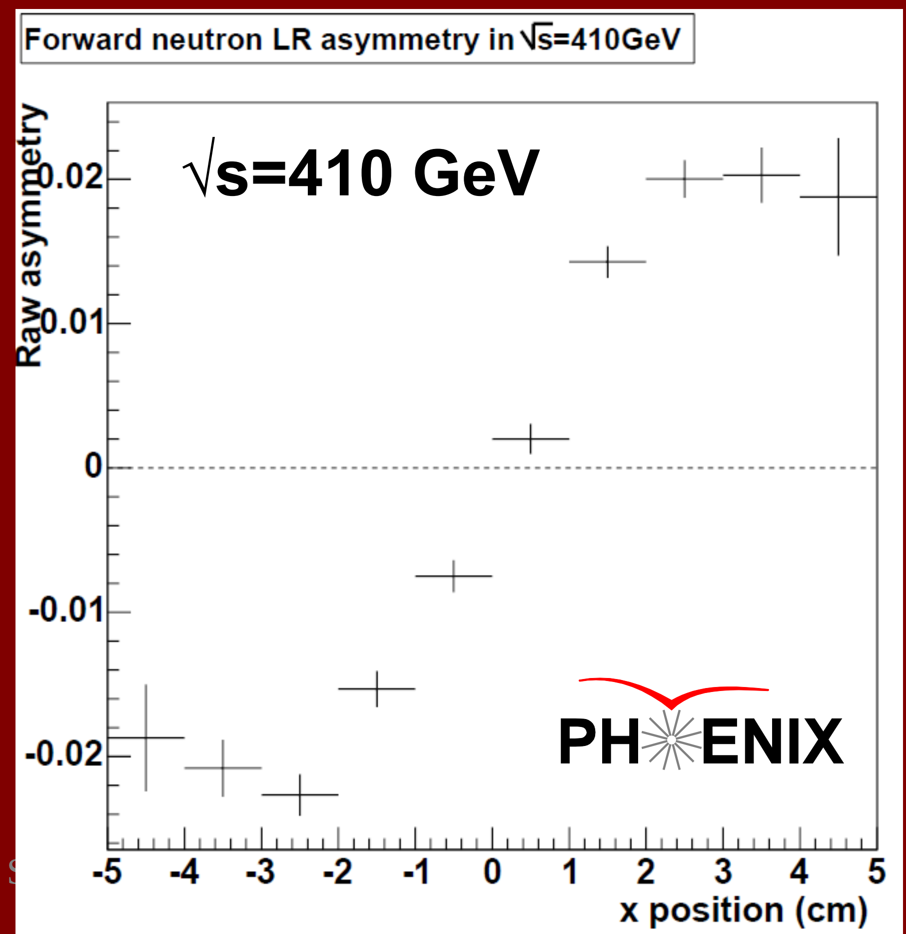


Forward neutrons at other energies

Significant forward neutron asymmetries observed down to 62.4 and up to 410 GeV!

$$A = \frac{N_+ - RN_-}{N_+ + RN_-}$$





Polarized Collider Development

Parameter	Unit	2002	2003	2004	2005	**2006**
No. of bunches	--	55	55	56	106	**111**
bunch intensity	10^{11}	0.7	0.7	0.7	0.9	**1.4**
store energy	GeV	100	100	100	100	**100**
β*	m	3	1	1	1	**1**
peak luminosity	$10^{30}cm^{-2}s^{-1}$	2	6	6	10	**35**
average luminosity	$10^{30}cm^{-2}s^{-1}$	1	4	4	6	**20**
Collision points	--	4	4	4	3	**2**
average polarization, store	%	15	35	46	47	**60-65**

Machine performance: Transverse spin running at PHENIX

Year	√s [GeV]	Recorded L	Pol [%]	FOM (P^2L)
2001 (Run-2)	200	.15 pb^{-1}	15	3.4 nb^{-1}
2005 (Run-5)	200	.16 pb^{-1}	47	38 nb^{-1}
2006 (Run-6)	200	2.7 pb^{-1}	51	700 nb^{-1}
2006 (Run-6)	62.4	.02 pb^{-1}	48	4.6 nb^{-1}
2008 (Run-8)	200	5.2 pb^{-1}	46	1100 nb^{-1}